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VOL. 8 MAY, 1921 NO. 3

EXPERIENCES WITH IRON IN THE PUBLIC WATER SUPPLY AT SHELBY, OHIO[1]

BY PHILIP BURGESS[2]

It is a well recognized fact that the presence of a considerable quantity of iron in a public water supply is objectionable but unfortunately there are comparatively few instances where such public water supplies have been developed and improved by purification, so that it is believed that the experiences of The Shelby Water Company, at Shelby, Ohio, in the development of a ground water supply containing considerable quantities of iron will be of general interest to the members of this Association.

Historical. The water works at Shelby were installed by the local water company in 1897 and the supply was obtained without treatment from drilled wells 40 to 60 feet deep, contained in a 10-acre tract bordering on Black Fork Creek and situated about one mile above the center of the town. Preliminary tests were made of the quality of the supply and the report of the analyst under date of October, 1896, contained the following:

> The water is very high in free ammonia, rather high in albuminoid ammonia, pretty well up in oxygen required. The water is a suspicious water. I should suspect it of containing animal sewage well fermented, but not exposed to

[1] Read before the 1920 annual meeting of the Central Stations Section at Detroit, Mich.

[2] Burgess and Niple, 141 East Broad Street, Columbus, Ohio.

oxidation. The practical absence of nitric acid may mean, however, that the free ammonia is largely due to nitrates reduced to ammonia by working through soil and rock containing reducing agents, possibly sulphide. This is theory, however, and a full investigation of these features will be necessary before this water could be considered safe, as the analysis, on the face of it, condemns it. This latter theory would be supported by the large amounts of sulphates (permanent hardness).

The analyst's statement indicating that the water was "suspicious" is of interest and indicates the general lack of information relative to the significance of organic matter in ground water supplies. Bacterial analyses have always indicated that the water supply at Shelby is practically sterile so that the high organic matter contained in the water is of no significance as regards its sanitary qualities. It merely indicates that the water takes up organic matter from the alluvial deposits, which are swampy and contain considerable deposits of a decayed vegetation, probably of prehistoric times.

Use of the water supply at Shelby soon indicated that it was generally very unsatisfactory for domestic purposes on account of its high iron content, and some 8 years later, in 1905, the company installed devices to remove the iron. These included aeration through perforated, horizontal, steel baffles in the top of the standpipe, sedimentation in the standpipe, and finally, filtration through two horizontal, steel pressure filters 8 feet in diameter by 24 feet long. The filters contained 18 inches of crushed quartz, having an effective size of 0.75 mm. The water was improved by these devices and the iron reduced from approximately 7 parts per million to about 0.6 to 0.8 part per million.

While associated with the Ohio State Department of Health, the author made an examination of the plant of the company in 1909 and numerous chemical and bacterial tests of the raw and treated waters were made at the plant, as shown in the table on the following page.

At that time the total consumption of water was from 250,000 to 300,000 gallons daily. The iron was reduced to a little less than 1 part per million and the consumers were generally satisfied with the quality of the supply. Subsequently the water consumption at Shelby has increased until, during the past year, it has been about 700,000 gallons daily, or double that during 1909, with the result that the removal of iron by the purification devices available was not at all satisfactory. The author was retained by the company to

design a new iron removal plant and subsequently his firm entered into a contract to construct this plant from the design furnished.

Iron removal plant. The general features or principles adopted in the new plant were similar to those in the old plant and comprise aeration, sedimentation and filtration. The supply is the same as that originally acquired, but the old drilled wells have been abandoned by the company and have been replaced by two dug wells,

Results of analyses of samples of water collected at Shelby, Ohio, January 14, 1909. (Parts per million)

DETERMINATIONS	RAW WATER	AERATED WATER	FILTERED WATER	
			At filter	In mains
Temperature, deg. C	10.9	10.1	9.9	11.5
Turbidity	0+	60+	10+	5+
Color	3		45	25
Free CO	48	28	24.5	22
Dissolved oxygen:				
Parts per million	0	7.8	7.7	7.5
Per cent saturated	0	69	68	69
Alkalinity	263	248	241	240
Incrustants	214	220	215	220
Total hardness	477	468	455	460
Total solids	713		713	
Loss on ignition	73		82	
Total iron (Fe)	6.5	6.7	0.85	0.60
Magnesium	31		31	
Chlorine	11.8	12.5	11.5	13.5
Oxygen consumed	3.65	2.58	2.13	1.90
Nitrogen as				
Free NH	5.80		0.180	
Alb NH	0.112		0.104	
Nitrates	0.002		0.002	
Bacteria per cubic centimeter	1		1	

approximately 45 feet deep. The new plant was designed for a normal capacity of 1,000,000 gallons daily. The aerator tower was based upon a normal capacity of 17 gallons per square foot per minute. The aerated water is retained in the sedimentation or reaction basin for a period of one hour. The filters have a normal capacity of 100,000,000 gallons per acre daily. The clear well holds 250,000 gallons of treated water, equivalent to 6 hours' storage. The filters are covered with a substantial brick superstructure. All of the basins and filters are of reinforced concrete.

During operation of the new plant, water is pumped by electrically operated centrifugal pumps from either of the wells and is discharged at the top of the aerator, through which it flows by gravity into the reaction tank, thence on to and through the filters into the clear well, from which it is pumped by electrically operated centrifugal pumps under about 60 pounds pressure, into the distribution system or standpipe. The latter is 16 feet in diameter, 130 feet high, and holds 196,000 gallons.

Aerator. The aerator comprises three horizontal trays containing crushed coke. The trays are 12 inches deep with 12-inch openings between trays. The bottoms are covered by wire screens containing $3\frac{1}{2}$ meshes per inch composed of iron wire 0.105 inch in diameter. The coke layers are 12 inches thick and are composed of particles ranging in size from $\frac{1}{2}$ inch to 3 inches in diameter. The trays are each 4.5 feet by 9 feet in section, with a total area of 40.5 square feet. The nominal rate of flow through the coke is 17.3 gallons per square foot per minute. The aerator is located over the inlet end of the basin and water is distributed over the top tray by two lines of perforated 8-inch cast iron pipe. The centers of these pipes are 8 feet 8 inches above high-water level in the basin.

Reaction tank. The basin or reaction tank is uncovered and is 14 feet by 43 feet by 10.5 feet deep. It holds 47,300 gallons so that the period of retention in the tank is 66 minutes.

Filters. The filters are 2 in number and are open gravity sand filters, each containing 240 square feet. The total filter area is 0.011 acre.

The strainer systems comprise 10-inch cast iron main collectors and $1\frac{1}{2}$-inch extra heavy galvanized iron laterals 6 inches apart. The laterals are perforated with $\frac{1}{4}$-inch round holes spaced in two rows, six holes per lineal foot of pipe.

Over the strainer systems is the filter gravel, placed to a total depth of 12 inches and comprised of particles ranging from $_1\frac{1}{2}$ inch to 2 inches in diameter.

Above the gravel, is placed 2 feet of filter sand with an effective size of 0.49 mm. and uniformity coefficient of 1.75. Considerable thought was given to the selection of sand of the proper size, and experience indicates that the sand used is entirely satisfactory.

The filters are washed through a 10-inch cast iron pipe connection from the standpipe and the rate of application of the wash water is from 20 inches to 24 inches rise per minute. The tops of the wash water troughs are 24 inches above the filter sand.

An unusual feature of the design is that high water in the clear well is 3 feet above the bottoms of the filters so that the total effective depth available for filtration is 3 feet, when the clear well is full. No controllers are provided in the effluent pipes on the filters. It is obvious that as the clear well becomes full, water backs up on the filters tending to reduce the head available for filtration and consequently to reduce the rate of filtration. This feature permitted considerable saving in the construction and operation of the plant. Moreover, the total head available for filtration has proven to be ample notwithstanding the fact that it is customary to keep the clear well full.

Operation of plant. The new iron removal plant at Shelby was first placed in operation on March 19, 1920, and has continued in successful operation since that time. It is of interest to note that the elimination of iron from the supply has been entirely satisfactory from the beginning of operation.

The actual results accomplished by the plant have been determined from time to time by analyses of samples collected by the superintendent of the company and shipped to the laboratory of The State Department of Health, at Columbus. The results of analyses so obtained are shown in the two accompanying tables. The analyses are not entirely satisfactory or significant on account of the fact that considerable time elapsed between the collections and analyses, but they do serve to indicate in a general way the character of the raw and treated waters.

In the first table are shown complete analyses of five samples collected on June 12 and August 27. The second table shows only analyses of iron and free carbonic acid. Two of the samples in the first table were obtained from well 2, and show considerable variation in the iron content of the water, which carries from 8.0 to 4.8 parts per million. Similar analyses in the second table show that the water in well 2 contained from 6 to 8 parts per million and samples collected from well 1 on March 18 showed that this water contained 16 parts per million. In general the iron content of the well water is high, ranging from about 5 to 8 parts per millon in well 2 and 16 parts in well 1.

Analyses of the samples obtained from the supply to the filters, on August 27, indicate but slight change in the chemical and physical qualities of the water as affected by aeration. Later tests made by Assistant Engineer Roberts of the State Department of Health indi-

cate that the dissolved oxygen content of the raw water was increased by aeration from 0 to 64 per cent saturation and that the free carbonic acid is decreased by aeration from 43 to 16 parts.

Results of analyses of samples of water collected at Shelby, Ohio.
(Parts per million)

SOURCE OF SAMPLE	WELL 2	EFFLUENT FILTER 1	WELL 2	SUPPLY TO FILTER 2	EFFLUENT FILTER 2
Date of collection	5/12/20	5/12/20	8/27/20	8/27/20	8/27/20
Laboratory number	27019	27018	27847	27846	27848
Sediment	Slight	None	Slight	Slight	Slight
Turbidity	50	0	40	50	10
Color	3	0	15	30	15
Nitrogen as:					
Free NH	0.16	0.16			
Nitrites	0.005	0.013	0	0	0.003
Nitrates	0	0	0.040	0.040	0.040
Oxygen consumed	0.3	0.3	2.15	1.75	1.65
Chlorine	10	16	14	15	14
Total alkalinity	330	270	328	320	318
Incrustants	350	360	365	370	370
Total hardness	680	630	693	690	688
Total solids	912	850	1076	1064	1162
Loss on ignition	245	231	116	144	198
Total iron (Fe)	8.0	Trace	4.8	4.8	0.3

Analyses of samples of water collected at Shelby, Ohio. (Parts per million)

DESCRIPTION	DATE OF COLLECTION	TOTAL IRON (Fe)	FREE CO_2
Well 1	3/18/20	16.0	46
Well 2	3/18/20	6.0	42
Supply filter 1	3/18/20	10.0	23
Supply filter 2	3/18/20	7.2	30
Effluent filter 1	3/18/20	0.1	8
Effluent filter 2	3/18/20	0.1	13
Office Water Company	3/18/20	0.4	13
Tap 132 E. Main St.	3/18/20	0.4	15
Well 2	5/16/20	8.0	
Effiuent filter 1	5/16/20	Trace	
Raw water	8/6/20	10.0	43
Filter supply	8/6/20		16

Note: The averages of several determinations of dissolved oxygen were as follows: Raw water = 0. Aerated water = 64 per cent saturated. Temperature of raw water = 10.5°C.; temperature of aerated water = 11.0°C.

Analyses of the total iron content as shown in the two tables are of especial interest and indicate that the filtered water at times contains only a trace of iron in the samples. The highest iron content shown at the plant is 0.3 part per million and from the mains in March was 0.4 part per million. The increase of iron in the main as compared with that in the filter effluents was caused by the former deposits in the mains. It will be of interest to see how long these deposits continue.

In general the operation of the plant has been entirely satisfactory and the filtered water supply has been always clear and free from suspended iron.

Experience indicates that the coke in the aerator tends to become coated with deposits of iron so that it is necessary to wash the coke every three or four weeks. This is done by washing the coke in place with a hose. But little sedimentation of iron occurs in the reaction tank, which is cleaned only once or twice yearly, and even at such times contains but a few inches of deposited precipitate. The filters are washed once daily at the rate of a little less than 24 inches rise per minute and generally for a period of 4 or 5 minutes. The total quantity of wash water used is only about 4 per cent of the quantity of water filtered, so that in this respect, the operation of the plant compares favorably with that of similar rapid sand filter plants provided to improve surface water supplies.

The contract under which the author's firm constructed the clear well and filters included all excavation and concrete structures, except the reaction tank, which was built by the company; also all pipe lines except outside cast iron pipe lines. It did not include the brick superstructure nor back filling and grading around the clear well and filter house. The total contract price for the above was $16,500. Mr. Bricker, president of the company, has advised the author that the superstructure cost about $1500 and the aerator and reaction tank about $3000 additional. It will probably cost about $800 to complete embankments and grading around the new plant, so that the total cost of the new plant was about $23,000.

In conclusion it should be noted that the recent experience of the company in providing a new iron removal plant has been entirely satisfactory and, in fact, has proven beneficial in a number of ways. The satisfaction to the officials of the company in providing a clear water supply free from objectional features, and to the consumers who are enjoying the new supply is very pronounced. Moreover,

the new plant has resulted in a marked increase in quantities of water sold, thereby increasing the revenues of the company due in part to the more abundant use of water by former consumers and in part to new consumers who have been attached to the property since the new plant is in operation. Mr. Bricker has advised the author that, during the past 5 months, the company has acquired more new consumers than it experienced during all the preceding 5 years.

Another feature of operation brought about by the new plant is that it is now very much easier to maintain service lines and meters than was formerly possible. With the use of raw water there were many instances where service lines became clogged with the deposits of iron thereby resulting in a loss of considerable sale of water and a considerable increase in expense entailed for maintenance of service lines. Similarly the iron contained in the water supply formed deposits on the meters, eventually with the result that there was a general reduction in the quantity of water sold, not always apparent to the officers of the company. There is no question but what the sale of water and revenues received therefrom were materially reduced by the above features, which are now eliminated by the operation of the new iron removal plant. In general the relations between the officials of the company and the consumers are much more satisfactory, a condition which has resulted in increased income and benefits to the company and increased enjoyment and use of the public water supply to the consumers. The benefits derived from the new plant have more than compensated the company for the expense entailed by its construction and operation.

POLLUTION OF RIVER WATER IN THE PITTSBURGH DISTRICT[1]

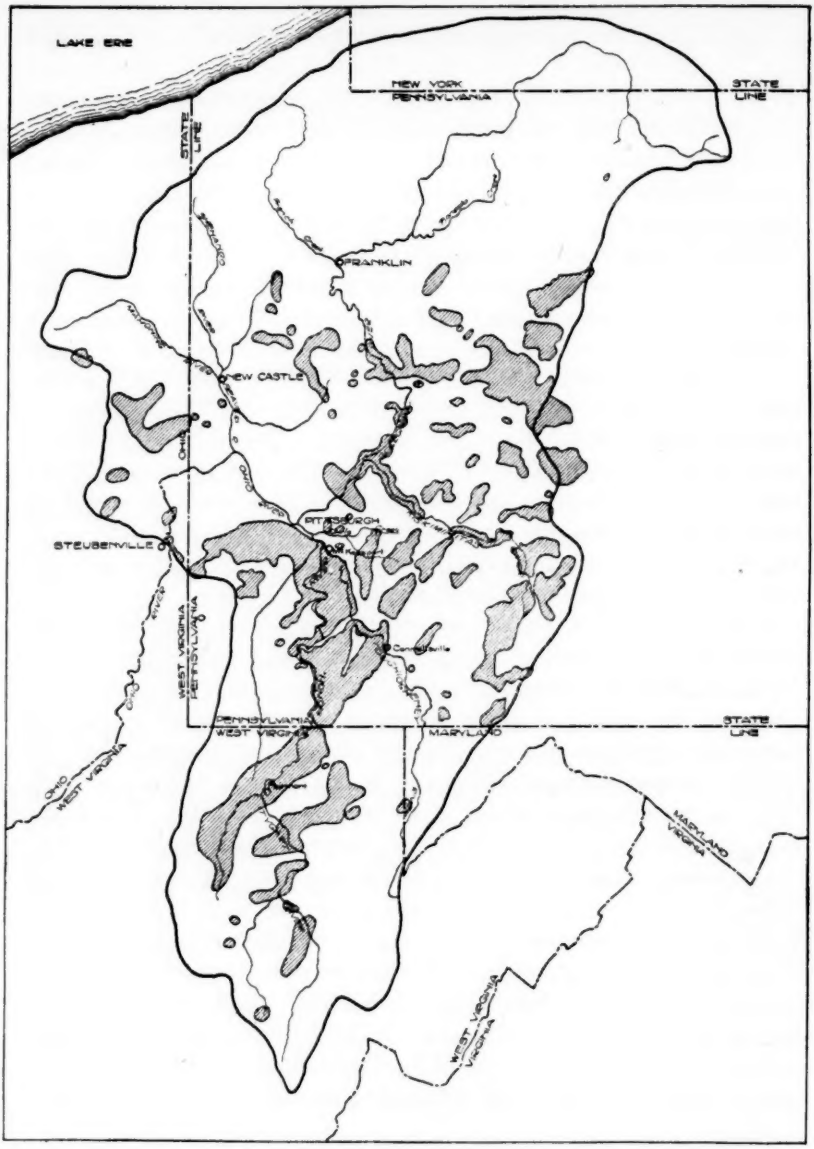
By C. M. Young[2]

The contamination of surface water with waste products of industrial activity is undoubtedly greater in the Pittsburgh industrial district than anywhere else in America. Probably there exists nowhere else in the world a region where so great an amount of waste material finds its way into streams. Some industrial waste is comparatively harmless, but that which appears in the streams of the Pittsburgh district is mostly harmful, mostly acid in character, and to be measured in terms of sulphuric acid.

The condition of acidity of streams has been approached so gradually that it has commonly passed almost unnoticed except by those immediately concerned with the use of water for boiler purposes or the supply of water to towns and cities. At length the change in character of stream waters became so apparent that the United States Engineer Office of the Pittsburgh district decided upon an investigation, which was commenced in 1914. The Engineer Office is the local branch of the Corps of Engineers of the War Department, which has control of all navigable streams. As the Ohio, the Allegheny, and the Monongahela are navigable, the War Department has control of them and of all their tributaries. The Pittsburgh district extends from Steubenville, Ohio, to the headwaters of all tributaries of the Ohio River which enter it above Steubenville, thus covering parts of Ohio, West Virginia, Pennsylvania, and New York. This is the territory covered by the invesgation under discussion and designated as the Pittsburgh District.

[1] This paper was prepared at the request of the Coal and Coke Committee of the American Institute of Mining and Metallurgical Engineers. It was finally decided, however, that the subject of water pollution was rather more within the field of the American Water Works Association than that of the Institute, and accordingly the Association was given the opportunity of publishing first in the Journal this valuable discussion of an important subject. Discussion of the paper is invited and should be sent to the Editor.

[2] Professor of Mining Engineering, University of Kansas, Lawrence, Kan.



PITTSBURGH DISTRICT OF THE ENGINEER DEPARTMENT, UNITED STATES ARMY

Approximate boundary shown by heavy line; territory included is the drainage area of the Ohio River above Steubenville. Cross-hatched areas are coal fields now being worked, according to the U. S. Geological Survey. In this district there were, in 1914, at least 1227 going coal mines, and hundreds of abandoned mines, 38 coal washeries, 116 blast furnaces, 63 sheet and tin plate mills, 15 tube mills, 13 wire mills, 49 oil refineries, 8 paper and pulp mills, 18 tanneries, numerous chemical works, numerous rolling mills, several thousand oil wells.

It was thus entirely proper that the investigation should be undertaken by a branch of the federal government, since the damage done in one state is sometimes caused by materials which enter the streams from other states, and since no other agency could well cover so large a territory.

The investigation had been carried on for some months when the author became connected with it, as a specialist, in the fall of 1914. The following discussion of conditions is based upon the material collected in the course of this investigation, a large part of which was collected before the author became associated with the work, largely by T. P. Roberts, Assistant Engineer, and A. F. Hoffman, Superintendent. It is published here with the consent of the District Engineer Officer of the Pittsburgh District, with the understanding that, while the material is derived from the facts collected in the course of this investigation, any opinions expressed are those of the author.

All of the following statements may be considered as made in 1914, but there has been practically no change in conditions since that time except a gradual increase in the extent of pollution.

Character of the pollution. The substances present in the river waters which are direct results of industrial activities are principally sulphuric acid and the sulphates of various metals, hydrochloric acid and chlorides, soluble organic matter and sulphite liquors from paper mills, decaying animal matter and tannates from tanneries, and salt water from oil wells. There is also a very large quantity of sewage from the various towns and villages scattered over the district.

Nature and amount of foreign matter in streams. In quantity of material and damage done, by far the most important constituent of the industrial wastes entering the streams is sulphuric acid, with the various sulphates formed by its combination with metals. This acid comes from various sources, the most important of which are mine water and waste pickle from tin plate, tube and wire mills.

Most of this acid pollution comes from the drainage of coal mines. Pyrite in the coal and the overlying rock is exposed by the processes of mining to the action of air and water. Under these circumstances it is changed by a process which may be represented by the following equation into sulphuric acid and ferrous sulphate:

$$2\,FeS_2 + 7\,O_2 + 2H_2O = 2\,FeSO_4 + 2\,H_2SO_4$$

No claim is made that this reaction exactly expresses the chemical changes taking place, but it is the simplest expression of the union of ferrous sulphide, oxygen, and water, to form the sulphuric acid and ferrous sulphate. We know of the presence of the pyrite, the oxygen, and the water, and of the presence in the effluent water of sulphuric acid and ferrous sulphate. Quite possibly other compounds are formed. Moreover, this reaction supposes the existence of pure pyrite and pure water, while we know as a matter of fact that the pyrite may contain traces of other substances than iron and sulphur, and that the water entering the reaction does carry dissolved substances, so that the reaction which takes place can not well be as simple as that expressed above. However, the most important of the immediate products of the combination are the sulphuric acid and the ferrous sulphate.

The further history of these two substances leads to various modifications. The sulphuric acid may leave the mine and enter a stream in its natural state, and very large quantities of sulphuric acid do so; on the other hand, it may come in contact with iron sulphide, with which it will react, forming hydrogen sulphide and ferrous sulphate, or through contact with calcium carbonate existing in limestone or in shale it may be converted into calcium sulphate, which substance also is present in large quantities in the streams of this region. The ferrous sulphate may come in contact with limestone, with which it will react with the formation of calcium sulphate and ferrous carbonate, the latter of which will immediately decompose, forming ferrous hydrate and giving off carbon dioxide.

The ferrous sulphate, unless previously precipitated, is eventually converted into ferric sulphate, approximately as follows:

$$2\ FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O$$

In this case half of the free acid is consumed. Analyses of mine water show that the free acid decreases as the iron is changed to the ferric condition. Possibly also oxidation occurs as follows:

$$6\ FeSO_4 + 3\ H_2O + 3\ O = 2\ Fe_2(SO_4)_3 + 2\ Fe(OH)_3$$

In some cases the concentration of ferric sulphate is sufficient to give the water a yellow or reddish brown color. In its course over the rocks of the district, in which limestones are common, this ferric sulphate is largely decomposed into calcium sulphate and ferric hydrate, the latter being deposited and covering the bottoms of the streams with its characteristic brown coating.

The ultimate course, then, of the pyrite which is found in the coal and the surrounding rocks of this district is conversion into sulphuric acid and ferrous sulphate, the latter changing with oxidation to ferric sulphate, the iron of the ferric sulphate finally being deposited as ferric hydrate and the sulphuric acid going into combination with calcium or magnesium to form calcium sulphate. Probably, however, the changes taking place are less simple than those outlined, and the substance which is deposited is probably in most cases not a simple hydrate but a basic ferric sulphate. It is useless to attempt to give the chemical composition of such a basic sulphate as it may take any of several forms. But the streams of this district are so fully charged in some places with the acid and the iron salts that the decomposition does not take place immediately and the streams themselves sometimes carry appreciable and damaging quantities of free sulphuric acid and of ferric sulphates, as well as large quantities of calcium sulphate.

The following analyses of mine water give an idea of the character and extent of contamination.

	GRAINS PER U. S. GALLON	
	Mine A	Mine B
$NaCl$	1.75	2.59
Na_2SO_4	13.12	10.34
$CaSO_4$	86.30	32.05
$MgSO_4$	56.54	22.09
SiO_2	2.10	2.33
Fe_2O_3 and Al_2O_3	12.07	51.54
Fe_2O_3	72.53	
FeO	6.65	16.50
Al_2O_3	93.23	
SO_3	26.30	93.44
H_2SO_4 (free)		213.50

Both of the mines are situated in the Connellsville district, but the amounts of acid discharged are very different. As is shown by the analyses, the amounts per gallon of sulphuric acid combined in iron and aluminum salts are approximately the same, while the amount of free sulphuric acid in the second is eight times as great as in the first. The maximum discharge from the first mine is 1,500,000 gallons per day and the minimum 750,000 gallons; while the maximum discharge from the second mine is 15,000,000 gallons per day

and the minimum 5,000,000. The first mine showed a minimum discharge of one ton of free sulphuric acid per day, and the second a maximum of 180 tons per day, the acid content of the water changing somewhat with the quantity of the latter discharged.

The average discharge of water per ton of coal in the Connellsville district has been variously estimated at from 3.50 to 5.47 tons of water per ton of coal. This gives some idea of the immense amount of acid, free and combined, which is discharged into the streams from the Connellsville district alone. The conditions of mines in other districts are not unlike those of the Connellsville district, as far as acidity of drainage water is concerned, and at the time when this investigation was carried on, there were known to be 1227 operating coal mines in the district. It can hardly be estimated that the average drainage is less than three tons of water per ton of coal, and as about 150,000,000 tons of coal were being produced in the district per annum at that time, the drainage from the mines was approximately 450,000,000 tons of water. While it is impossible to determine the actual acid content of this water, it seems safe to assume that, taking into consideration free and combined acids, the total discharge does not amount to less than 200 grains per gallon, or approximately 7 pounds of sulphuric acid per ton of water, either free or combined in salts. With this rate of discharge, there would be a flow of 1,575,000 tons of sulphuric acid into the streams of the district per year, or approximately 4300 tons per day. There is also a considerable discharge from the large number of abandoned mines of the district, some of them of large size.

A large amount of acid also comes from the waste dumps of coal washeries. At the time of the investigation approximately 6,000,000 tons of bituminous coal were being washed per year, and it was estimated that the refuse from these would contain some 90,000 tons of sulphur per annum. Of course, the oxidation of this material to acid is not immediate, and probably it is less rapid than the accumulation of the material. Also, in many cases these refuse dumps will be burned and the sulphur volatilized, the iron being left behind as oxide. Nevertheless, these refuse piles contribute to the streams of the district very large quantities of sulphuric acid and its salts.

The streams of this district drain the coal fields of northern West Virginia, and all of western Pennsylvania. There is some mining

in eastern Ohio in the district under consideration and numerous abandoned mines, but most of the Ohio mines are south of Steubenville and therefore outside the district. These southern Ohio mines contribute largely to the pollution of the lower Ohio. The greatest part of the present development is on the watershed of the Monongahela, but development is increasing on the watershed of the Allegheny.

There is concentrated industrial activity along the streams of the district, quite largely associated with the production of iron and steel. This extends along the Monongahela for some miles above Pittsburgh and up the Mahoning to Warren, Ohio. There are also various other activities scattered through the district. The topography is such that mine water commonly finds its way almost directly to the streams without the opportunity for precipitation or oxidation which would be given by slower percolation through the soil. The topography also restricts the railroads to the stream valleys and this in turn restricts industrial plants largely to these valleys. There is thus concentrated in the valleys which carry the water, already somewhat polluted, an industrial activity which not only adds to this pollution but which is seriously injured by it, inasmuch as most of the industrial plants have to use the stream water for boiler purposes and in some cases for cooling purposes.

An appreciable quantity of acid in the water of some of the streams comes from the pickling liquors used for cleansing iron in the manufacture of sheets, tin plate, tubes, and wire. At the time of the investigation there were in the district at least 63 sheet and tin mills, 15 tube mills and 13 wire mills. When running at full capacity, these would use respectively a total of about 700, 200, and 400 tons of sulphuric acid per day, or approximately 390,000 tons per annum. Most of the sulphuric acid is converted into iron sulphate, and it is sometimes recovered in that form, but it seems to be the common custom to allow it to flow into the streams, though in some cases the waste acids are dumped onto slag heaps, where the acid itself and its iron salt will be converted into the calcium salt.

At least 49 oil refineries were located in the district, which used large quantities of sulphuric acid, though no definite figures could be collected of the amount used. Various other plants, such as paper mills, rolling mills, tanneries, and oil wells discharge waste into the streams, but their total contribution to the pollution, while

considerable in itself, is small in comparison with that of the mines and the tin, tube, and sheet mills.

There is no definite figure of the relative amounts of acid and acid salts contributed by the mines and by the mills mentioned, but it is certain that the discharge of acid from the mines is very much greater than that from the mills. On the other hand, most of this mine water has opportunity for neutralization before the more thickly settled part of the district is reached, because the streams are naturally alkaline. Nevertheless, the contamination from mine water is important, because if it were not for this, the streams would reach the concentrated industrial area strongly alkaline, and the amount of acid added to them in their flow through this district would not, under present conditions, be sufficient to make them acid, but reaching the district already partly or wholly neutralized, or even acid, the addition of acid waste by the manufacturing plants makes them acid or adds to the acid already present.

In the course of this investigation numerous samples were taken from the Allegheny, the Monongahela, and the Ohio and the flow of the streams recorded for the time of the sampling. The flow of the stream was estimated in each case from the height of water over the dam and records of this are kept constantly in the Engineer Office. Most analyses were for free acid and decomposable salts only. Various other analyses were collected, some of them made by the Public Health Department, and large numbers were compared.

In the case of those analyses made for the investigation under discussion, free acid was determined by titration with methyl orange as an indicator. Decomposable salts and free acid together were determined with the use of phenolphthalein, after boiling to remove carbon dioxide, and the result calculated as sulphuric acid. It is possible for water to be neutral to methyl orange while acid to phenolphthalein, in which case all the acidity would be present as decomposable salts of iron and aluminum. There are cases also in which methyl orange shows alkalinity, while phenolphthalein shows acidity, in which case the acidity to phenolphthalein plus the alkalinity to methyl orange represents the decomposable salts. In case the methyl orange shows acidity and phenolphthalein a greater acidity, the free acid is shown by the methyl orange and the decomposable salts by the difference between that and the total acidity shown by phenolphthalein. The following extract from the analyses and records of stream flow indicates the conditions encountered.

Sample extract from analyses and records of stream flow

NUMBER	DATE, 1914	ORIGIN OF SAMPLE, LOCK NUMBER AND RIVER	ACIDITY −, ALKALINITY +, PARTS PER MILLION		DISCHARGE PER SECOND	TONS PER 24 HOURS	
			Methyl orange; free acid	Phenolphthalein; free acid and decomposable salts		Free acid	Decomposable salts
					cu. ft.		
1	May 21	No. 2 Mon. R.	0.0	−40.0	3,519	0	380.0
2	May 21	No. 2 Alleg. R.	+10.0	−3.0	22,878	0	803.0
3	May 21	No. 3 Ohio R.	+9.0	−3.0	26,397	0	855.0
4	June 6	No. 2 Mon. R.	−34.0	−78.0	4,000	367.2	475.2
5	June 6	No. 2 Alleg. R.	+19.2	+6.0	13,918	0	498.3
6	June 6	No. 3 Ohio R.	+16.4	+4.0	17,981	0	602.0
7	June 26	No. 2 Mon. R.	−80.0	−279.0	2,250	486.0	1209.0
8	June 26	No. 2 Alleg. R.	+5.0	−18.0	11,300		701.7
9	June 26	No. 3 Ohio R.	+18.0	0.0	13,650		663.4
10	August 26	No. 3 Mon.	+9.75	−11.7	600		34.7

Group 1, 2, 3 shows that a total of 1183 tons of acid and decomposable salts calculated as acid passed Locks No. 2 on the Allegheny and Monongahela, also some 200 tons was probably added from industrial plants below these locks; yet only 855 tons appeared at Lock 3 on the Ohio. Something over 500 tons had disappeared, neutralized by sewage and by treatment for industrial uses.

Group 4, 5, 6 shows a large amount of free acid in the Monongahela, and the disappearance of a considerable amount of the acidity above Lock 3 on the Ohio.

No. 7 shows a high acidity, probably due to the flushing of pools by a slight rise. A few days before, the discharge had been only 750 second-feet.

The treatment of the water for boiler use commonly renders the water alkaline, and the discharge of this water into the streams after its condensation has a considerable effect in decreasing the total acidity. In this way the intense industrial activity is of benefit to the streams, but the cost of this treatment of feed water is a severe tax on the industries.

Analysis 10 seems to illustrate this, as it shows a condition of very low acidity at a time of low discharge. As the flow from mines is much less variable than the stream flow and the amount of acid discharged fairly uniform, concentration of acid at periods of low

water would be expected. The probable explanation of low acidity in this case is neutralization for boiler use and by influx of alkaline sewage. The stream showed 118 tons of acid combined in stable salts, mostly sodium sulphate, which indicates feed water treatment.

It is estimated that about one fifth of the acid occurring in the Pittsburg district is free sulphuric acid. About one half of the acid is combined with calcium and magnesium or with alkalies, into salts which do not decompose under boiler conditions, and the remainder is present as sulphates of iron and aluminum, which do decompose in the boilers.

It is probably safe to estimate that four-fifths of the sulphuric acid and sulphates entering the stream are neutralized by the natural alkalinity of the water before reaching Pittsburgh. At the present time the Allegheny River rarely shows free acid, the Monongahela shows free acid most of the time, and the Ohio River only during periods of low water. All three of these rivers show considerable quantities of acid in the form of decomposable salts of iron and aluminum.

The effect of development of the coal industry is plainly shown by the conditions of the two streams, the Monongahela with its largely developed coal industry commonly showing free acid, while the Allegheny rarely shows it. However, the mining industry is being developed in the drainage area of the Allegheny, and the periods of acidity of that stream are becoming more frequent and prolonged.

Sewage discharged into the streams. To a considerable extent the acid which reaches the more thickly settled parts of the district seems to be neutralized by sewage, and considerable amounts disappear in the passage through the Pittsburgh district.

The average daily sewage discharge from a district containing 590,000 persons was found by the Department of Health of Pittsburgh to be 164 gallons per capita. On this basis the sewage from the entire district was estimated at 900 second-feet. The average alkalinity of the sewage of Pittsburgh was found to be 94 parts per million, and assuming this alkalinity for the entire district, the total discharge provides sufficient alkalinity to neutralize 228 tons of free sulphuric acid or its decomposable salts each 24 hours. There are times when even more than this is neutralized.

The presence of the mine and mill waste in the rivers of the district has been in one way a very fortunate thing for the city of Pittsburgh, as this acid has reacted with the sewage in such a way

as to precipitate it and prevent the putrefaction which would otherwise have taken place in the rivers. This seems to be the one advantage of the presence of acid in the streams, all its other effects being deleterious.

Damage from acid pollution. The presence in the water of the acid and its combinations leads to many serious inconveniences and to great expense. No attempt is made here to mention all the harmful effects of pollution, only those being considered which are of greatest importance.

Probably the most conspicuous effect of the acid is found in the use of water in boilers. All forms in which the SO_4 reaches the boilers seem to be harmful. The formation of scale by calcium and magnesium salts is well known. The effect of the free sulphuric acid and of that combined in iron and aluminum salts is more harmful. The free sulphuric acid readily combines with iron in the boiler to form ferrous sulphate. This is oxidized, if there is oxygen present in the water, to ferric sulphate, which decomposes to form ferric hydrate and sulphuric acid, the acid again attacking the iron and this process being continued as long as the oxygen supply holds out. The ferric and aluminum salts which are present in the water are decomposed under boiler conditions, acting as does the iron sulphate formed in the boiler from the free sulphuric acid, all of the SO_4 eventually combining with the iron in the boiler to form a sulphate, which is decomposed into hydrate if oxygen is present.

An illustration of the damage caused by the acid may be taken from the experience of the railroads. One of these, whose tracks are along the Mahoning and Youghiogheny Rivers, was maintaining fifteen plants for the treatment of locomotive water, these plants costing $250,000, and was spending $20,000 per year for chemicals. The total cost of operation, including chemicals, overhead expense, labor, 6 per cent interest on the investment, depreciation and repairs, brought the cost of treating water up to $60,000 per annum for the 258 locomotives of that company operating in the district.

Notwithstanding this treatment, great damage was caused. With use of good water, locomotive boiler tubes should last from twelve to fifteen years, but under the existing conditions they were lasting from twelve to fifteen months, at which time they had to be safe ended, and in five or six years had to be replaced. The annual cost of tube trouble per locomotive was given as $225, and $155 was considered the annual loss chargeable to impurities in the water.

It was also found that fire boxes had to be removed twice as frequently as with good water. This requires that the locomotive be out of commission for three weeks, and costs $1500. The railroad mentioned was spending about $300 per annum per locomotive for this purpose, about $150 of which could fairly be charged to the condition of the water.

Locomotive boilers under normal conditions should do service for about twenty-five years, but in this district they are rendered unserviceable in fifteen years or less. Assuming the cost as $3500, the annual deterioration due to bad water amounts to $93.33.

Because of the heavy deposits of chemicals, scale, mud, etc., it is necessary to wash boilers frequently, this operation costing about $2.50. As each boiler is washed on the average of 24 times per year, the annual cost amounts to $60 per locomotive. This is small, but it is twice as great as is necessary with ordinary water, and the condition of the water is therefore chargeable with an expense of about $30 per locomotive per annum for this purpose.

There is a greater loss, however, than any of these which have been mentioned, namely the waste of fuel caused by scale, and the necessity of blowing off large quantities of steam and hot water. The mechanical engineer of the railroad mentioned estimated that the fuel loss, in excess of the normal, was about $1.50 per day, as a result of scale. In order to make this loss as small as possible and to reduce risk to the boiler, the boilers are blown off frequently. During dry weather it is not unusual to blow off a boiler three times in a trip of 100 miles, while during other months of the year it is done about once in 100 miles. The resulting loss of fuel and water amounts to roughly $1.60 per day. There are also various other losses which can not readily be estimated, one of the important ones being the failure of locomotives on the road because of boiler leaks, which results in delay of traffic and loss of time on the part of train crews. A summary of the above losses for the one railroad amounts to $1,618 per locomotive per year.

Another railroad in this district, which was then using 250 locomotives, estimated the cost of water treatment also as $60,000 per year. The two railroads together suffer a known loss of about $800,000 per year, but it will be noticed that this is not the total loss, because the many delays incident to trouble caused by bad water could not be estimated and are not included.

The two railroads mentioned are the ones that suffer the greatest damage. There are others in the district, and none is free from the effects of the bad water, though the Pennsylvania railroad has largely overcome this trouble by supplying water from the mountains to the east.

There are also several hundred locomotives of various sizes at the industrial plants, the United States Steel Corporation alone having nearly as many standard gauge locomotives as the second railroad mentioned, as well as a large number of small, narrow-gauge locomotives.

The damage is not confined to railroads, as every producer of steam suffers from it. The conditions are such that it has become necessary to treat all boiler feed water drawn from the rivers of the district. While no complete catalog of the power plants of the district has been made, it has been estimated that some 4,500,000 horse power is developed by steam within a radius of 60 miles of Pittsburgh. All the large manufacturing establishments maintain water-softening plants to neutralize the feed water, and in some of the steel mills there are additional plants for neutralizing the cooling water, in the latter case no attempt being made to remove the scale-forming constituents.

The capital invested in water softening plants in the Pittsburgh district is several million dollars, and the annual cost of treatment, while not known accurately, is certainly very large.

One fact which leads to difficulty in treating water in this district is that the character of the water is not constant but is very variable. As an illustration of this, it may be stated that on some days and under certain conditions of the Youghiogheny River, the chemists at the McKeesport water works test the water every hour, in order that the treatment may be suited to the condition of the entering water.

The Youghiogheny suffers more from contamination with mine water than any other of the larger tributaries of either the Monongahela or Allegheny. At times of low water practically the whole volume of flow of this stream is made up of mine water, and under such conditions it is so badly contaminated that it would not be used either for boiler purposes or domestic use, if other supplies were available. As an illustration, on October 14, 1914, the raw river water at the McKeesport water works showed a hardness of 704 parts per million and contained over 16 grains per gallon of

sulphuric acid and nearly 12 grains more sulphuric acid in the form of aluminum and iron salts, the latter of which decompose under boiler conditions. This means that the river contains a total acidity of over 28 grains per gallon and over 41 grains per gallon of incrustants. A 100 horse power boiler, using such water without treatment, would take in from 32 to 40 pounds of sulphuric acid each 24 hours.

The ordinary treatment for boiler water is with lime and soda ash, but with water such as that of the Youghiogheny the amount of sodium sulphate formed is so great that foaming soon occurs and it is necessary to blow off the boiler frequently.

Water works. It has already been stated that all water used for industrial purposes along these streams has to be treated. The same statement is true of water used for domestic purposes. Generally speaking, the acidity of the streams reduces the bacterial growth, but it has not been found safe to assume that because a stream is acid it contains no harmful bacteria. These treatment plants are operated at considerable cost.

The treatment of the water of the Youghiogheny for the city of McKeesport has already been referred to. The supply for the city has been taken from the Youghiogheny since 1881. When the original plant was constructed the water supply was very satisfactory, but since then developments on the watershed have been such that the water has become almost intolerable. The fact that the river water is subject to sudden and important changes required the erection of a complicated plant. This plant was put in operation in October, 1908. During the preceding summer the corrosive action of the water on the pumps, the pipe system and the plumbing fixtures was very serious, and because of leakage it became almost impossible to supply water for the city. The results of operating the plant were very satisfactory, and during the first three months of operation the daily consumption was reduced from about 7,000,000 gallons to less than 4,000,000 gallons, largely through saving of leakage. The cost of chemicals was high, but considered insignificant in comparison with the saving in plumbing, soap, etc. The rapid variations in the character of the water of the Youghiogheny are shown by the following table, giving the analyses of water made for the water works plant in one day. Probably this rapid change was due to waste liquor from an industrial plant not far above the water works.

TIME	TOTAL HARDNESS	ACIDITY, PHENOLPHTHALEIN	ACIDITY, METHYL ORANGE
	p.p.m.	*p.p.m.*	*p.p.m.*
8.00 a.m.	118	90	45
11.00 a.m.	224	150	70
12.00 a.m.	430	300	160
1.00 p.m.	508	340	210
2.00 p.m.	440	230	140
3.00 p.m.	348	160	90
4.00 p.m.	300	110	40
6.00 p.m.	173	80	35
7.00 p.m.	152	70	30
11.00 p.m.	116	65	40

It is the understanding of the author that the city now obtains water from the Monongahela, and the fact that the use of Youghiogheny water had to be abandoned is confirmation of the seriousness of the condition.

Perhaps the situation of the city of Pittsburgh is even more serious. Some years ago an extensive filtration plant was built at Aspinwall on the Allegheny River a few miles above the city. This is a sand filtration plant, depending for its action upon the stoppage by sand of solid matter in the water, and this depends upon the collection of colloidal material on the sand beds. This method of filtration is efficient only with alkaline or neutral water and fails in case of acidity. Unfortunately periods of acidity will become more frequent as the mining industry develops in the valley of the Allegheny and apparently it will be only a few years until it will be necessary to largely add to this plant if the water is to be treated in such a way as to make it safe for domestic use.

Miscellaneous losses. There are various other losses chargeable more or less directly to the pollution with acid which need not be taken up in detail but can be suggested. Among these is that of house plumbing. This matter was investigated and the lowest estimate which could be placed upon the damage due to acidity, founded upon the opinions of plumbers and dealers in plumbers supplies, was $10 per annum for each house. In 1910 the district had a population of 3,167,000, which would require in the neighborhood of 500,000 houses. Assuming that only 300,000 houses should be estimated as having plumbing that would be affected, the damage to these would amount to $3,000,000 per year.

There are also many office buildings and manufacturing plants at which the plumbing was damaged. One rolling mill, taking its water from the Monongahela, was obliged to renew its service pipes on an average of once every three weeks during the summer of 1914.

Considerable, though inestimable, damage is done to the clothing of inhabitants of the district, especially to such clothing as is sent to laundries. The hardness of the water increases the consumption of soap, and when attempts are made to overcome this hardness by addition of chemicals, the clothing is very greatly damaged. The laundries are also inclined to use bleaching powder in excess and clothing is very greatly damaged thereby.

The effect of this contamination of the streams upon organic life is very marked. Fish can not live in water containing free acid or any appreciable quantity of ferric sulphate; therefore the Monongahela has no fish life, the Allegheny has very little, and there are no game fish in the Ohio from Pittsburgh to Parkersburg, 183 miles below Pittsburgh, where the Little Kanawha enters. At this point a few game fish are found, but there is no good fishing in the stream until Point Pleasant, 263 miles below Pittsburgh, is reached. The Shenango has fish above New Castle, and some are found below the town. The Youghiogheny is entirely without fish, except perhaps in the upper portions above the coal fields.

As illustrative of the seriousness of the water situation from the point of view of the steel industry, the following notes on the water treatment at one plant may be given. This is one of the largest steel plants in the world, having eleven blast furnaces, with a daily capacity of about 500 tons each. When operating at full capacity this plant pumps from the river from 50,000,000 to 60,000,000 gallons per day. During ordinary conditions of the river only the water intended for boiler use is treated; during periods of high acidity the entire supply is treated with lime, enough being used to neutralize the high acid without any attempt at complete neutralization. When the plant is running at capacity, about 3,000,000 gallons of water are used per day in boilers, and about 40,000 horse power developed. The treatment of boiler water was commenced about 1904. During ten months in 1914 the water treated amounted to 768,838,000 gallons, the soda ash used was 1,206,655 pounds, or 1.555 pounds per 1000 gallons; and the lime 290,175 pounds, or 0.377 pound per 1000 gallons.

In view of the very serious loss and inconvenience resulting from the extensive pollution of streams in the Pittsburgh district it is regrettable that no simple remedy presents itself. While it would be possible to require that such harmful substances as have been mentioned be kept from the streams, such a course would apparently impose a considerable hardship upon the industries concerned, especially upon coal production. The water from the mines can not be kept out of the streams, and little attempt has been made to purify it. A beginning[3] has, however, been made in this direction and the H. C. Frick Coke Company, is operating a plant for the recovery of by-products from mine water.

In Germany a comparable condition of the Emscher, on which Essen is situated, has been met by the organization of a federation for the construction and maintenance of the necessary means for keeping suspended matter out of the streams.[4] Apparently nothing has been done to prevent substances in solution from entering the streams; possibly the flow of the Emscher is so small in comparison with that of the Rhine which it enters, that its purification was not considered worth while, and possibly it was not considered practicable.

It is the belief of the author that farther research is desirable with the purpose of extending the extraction of valuable substances from mine water. If this can be practicably done the contamination of streams with acid will be reduced, possibly to such an extent that the natural alkalinity of the water will assert itself.

The neutralization of the wastes from manufacturing plants is a much less difficult matter and should not be so expensive as to seriously burden the industries concerned.

Summary. Acid pollution of streams of the Pittsburgh district is due principally to water from coal mines and to manufacturing waste.

There is extensive discharge of sewage, the alkalinity of which partly neutralizes the acidity of the streams.

Fish life is absent from the streams, or is rapidly disappearing.

All water used for boiler purposes must be treated.

Water for municipal supply must be treated.

[3] C. M. Young, Valuable by-products of coal mining, *The Coal Industry*, Vol. 1. S. D. Tracy, Mine water neutralizing plant at Calumet Mine, *Am. Inst. M. & M. E.*, Lake Superior meeting, 1920.

[4] Charles Saville, The Emscher Federation and the statute under which it operates, *Eng. Rec.*, vol. 66, p. 518 (1912).

COMMITTEE ON PRIVATE FIRE PROTECTION SERVICES[1]

Minority Report by E. V. French[2]

The Committee on this subject made a report to the Buffalo Convention in June, 1919. I regret exceedingly that absence in France for a year on fire protection work for our army prevented my sharing in the work of this Committee, so that I was able to attend only one or two of the preliminary meetings.

The year has been an exceedingly busy one so that I have been absolutely unable to give this matter the study needed before covering satisfactorily several features upon which it seems to me desirable to bring out some further points, though considerable time has actually been spent upon the matter.

The report, as a whole, is, I think, the broadest and fairest presentation of the subject which has yet been made. I agree in general with the treatment of the physical questions which cover the first forty pages of the report as printed. In Division B, Fiscal Questions, which takes up the remainder of the report, there are some broad questions which it seems to me have not yet been worked through to final and surely correct conclusions. In my own field we propose to continue our investigations in a comprehensive manner and shall expect some months hence to be able to present some further ideas which, I believe, will be helpful in bringing this part of the problem to a final and generally satisfactory conclusion.

Returning to the physical questions, I would bring up the following additional points, using the divisions and headings of the main report.

(2) How shall the water purveyor be protected, etc.

Speaking from the side of fire protection engineering, I think we should recognize the desirability of more scientific and business-like operation of water departments, which means that the responsible

[1] Submitted informally at the Montreal Convention.

[2] President Arkwright Factory Mutual Fire Insurance Company, 31 Milk Street, Boston.

officials must have proper knowledge and control of all uses of water. Several of the special meters which have been designed for fire services will give the information and control needed. Their use, however, is being pushed in some cases without discrimination as to the real needs, so that the large cost which they entail and the additional shut-offs for occasional repairs which they cause are being imposed where simpler means would give all the safeguarding necessary.

The thing which would most help this part of the problem would be the development of a simple and inexpensive device which would show about what passes through a fire service connection but without the need of the accuracy required for continuous commercial metering. But little water ever passes through the majority of fire service connections so that a device which would fulfill the above requirements would do all that is necessary in most cases. I believe we should encourage inventive minds to work in this direction and that it will be found possible to produce something which will fill this need satisfactorily.

The alarm check valve method suggested in the main report can be used to advantage in some cases but in other instances they have given trouble by false alarms so as to make such a method unsatisfactory.

Cultivation of common sense coöperation between water departments and the owners of private fire systems will help greatly and with this in many cases a good system of valve sealing or the adaptation of the methods which the Committee suggest, will cover all needs, at least until some good and simple device, which can be applied like an ordinary meter, is available.

(3) HOW SHALL PRIVATE FIRE PIPES BE CONTROLLED, ETC.

The general problem is well stated in the main report but it is desirable to recognize more fully the many large manufacturing plants which have had fire protection for years and where there are mill yards giving space for the safe location of controlling valves. It is in this class of property that private fire protection was first developed and in which it has reached its largest use. In practically all these cases it is feasible to get such certain control that there need be no fear of serious bleeding of a public supply.

This question of control is an engineering problem which must be worked out in many instances with due consideration to the special conditions but there is rarely any difficulty in conforming to the fundamental principles that reliable means of control should be provided on all outlets from public water systems.

It is desirable to recognize the growing importance of private fire protection in the control of the great fire waste of the country and after proper physical arrangements are made, it will be necessary for up-to-date water departments to have men trained who will go to fires the same as members of the public fire departments and see that the water supplied to fire systems is controlled properly and with due regard to both the burning property and the community as a whole.

(4) WHAT LIMIT SHOULD BE PLACED UPON THE SIZE, ETC.

The fundamental point here is to bring about the use of the water available for fire-fighting in the way which will most surely extinguish fires, prevent the destruction of property and the possible spread of a fire to conflagration extent and great community loss. The proposed 50 per cent limit would in some cases accomplish this, in others it would not safeguard the general water system, and in some further instances it would restrict the flow unnecessarily with no benefit to the system as a whole and with serious possible detriment to the particular property needing protection.

Such a limit would, therefore, have to be used with discretion and again it is necessary to apply good engineering knowledge and judgment. For the best results chief reliance must be upon proper means of control and a good system of handling such means of control in case of emergency, all along the lines outlined briefly in the preceding section (3). Here also it is possible that ingenious minds will devise some simple and reliable valve which will provide reasonable automatic control over such conditions but here again, as so often has been the case, it is difficult to find anything which will replace satisfactorily intelligent human control.

(5) WHAT MEANS SHALL BE ADOPTED TO PREVENT POLLUTION

The importance of this matter has been well set forth in the main report. Today there is nothing better than the simple arrangement of tandem check valves of special design illustrated fully in the

report coupled with regular and competent inspection of these devices. In our own field this arrangement was first used ten years ago and there are now over 500 services so equipped. They are tested regularly by our inspectors and we have never yet found a case where both check valves leaked. This method is not only the best now available but gives practically positive protection. It is a good example of the development and use of a simple idea and shows what can be done where such problems are taken hold of intelligently and pushed with persistence.

. . . . . .

The work of the Association has resulted in a distinct advance in the consideration of this general problem. I hope that the Convention will be willing to continue the Committee in order that a number of points regarding these physical questions may be developed further and more particularly so that we may have opportunity to study more fully the broad fiscal questions and arrive, as I believe will be possible, at final conclusions which can be adopted unanimously. With this done an important step will have been taken and a practical standard adopted for this whole important problem.

DEVELOPMENT OF THE F. M. DOUBLE CHECK VALVES AS A SAFEGUARD FOR PUBLIC WATER SUPPLIES[1]

By H. A. Burnham[2]

The subject of conservation is always of great interest and importance and it arises with respect to both life and property whenever we consider protection against fire. As a result of over fifty years' experience in protecting large manufacturing properties in about one thousand cities and towns in twenty-nine states and four provinces of Canada, it is believed the following information will be of value to those who are concerned with the arrangement of private fire supply from public mains.

Function of public water systems. A public water system has two distinct and generally recognized functions; one is to provide water for domestic and industrial purposes, the other is for extinguishing fires. These functions are brought into proper relative adjustment through the coöperation of the sanitary engineers and the fire protection engineers.

In a matter so vitally concerning communities at large as this relation between public health on one hand and the loss of life and property by fire on the other hand, every community should carefully consider all the available facts before forming its opinion as to its needs, and for that purpose the following facts are presented as having an important bearing on this question. These facts relate entirely to a particular kind of safeguard for public water supplies, known as the F. M. double check valve equipment.

Sprinkler systems. A public water supply exercises its fire extinguishing function in the most efficient manner through automatic sprinkler systems. Very briefly described these consist of many sprinkler heads, so-called, supported near the ceiling by a system of pipes filled with water under pressure. When a fire heats the head sufficiently, the solder—which keeps the head closed at ordinary

[1] Read before the Canadian Section at Toronto, February 4, 1921. Discussion is requested and should be sent to the Editor.

[2] Engineer and Special Inspector, Associated Factory Mutual Fire Insurance Companies, 31 Milk Street, Boston, Mass.

temperatures—melts and allows water from the pipes to spray onto the fire. The heads are spaced 8 or 10 feet apart over the entire area to be protected. The continuity of the water supply at good pressure is, of course, a vital factor in the capability of the sprinkler to control or to extinguish the fire, and for this reason it is often necessary to guard against interruption of this service by providing a secondary supply, often in the form of a fire pump drawing water from other sources than the public works.

To use these supplies automatically in a single system of piping, it has been the practice for a great many years to use check valves on both supply pipes in order that water pressure from the higher source may not be lost through the lower.

Need of improvement recognized. The occasional failure of the old style check valve, buried out of sight in the earlier days of the development of automatic sprinkler protection, showed that improvement was needed in this feature if fire protection engineering was to keep pace with sanitary engineering in the matter of safeguarding against contamination at every point.

The very large majority of water works officials are keenly alive to their responsibilities in the matter of furnishing the most efficient fire protection possible, and it is reassuring to know that in practically all cases which are reported from time to time of contamination of the water supply the action of the responsible parties has been prompt in locating and removing the cause of the trouble and in taking measures to prevent its recurrence.

As a result of the desire on the part of public officials to obtain absolute freedom from contamination, there have been but very few cases where the obligation to furnish efficient fire protection has been denied by requiring complete physical severance of the sprinkler systems from the public mains and consequent lowering of the standard of fire protection.

Improvement accomplished. Having fully recognized the need of improvement for the sprinkler connections as long as twelve years ago, fire protection engineers applied to this problem the principles of superior mechanical construction and complete accessibility. The result has been, as stated by an eminent sanitary engineer, that the public water connection to a sprinkler system having a dual supply can be maintained so that the danger of contamination is reduced to a point where it is of less importance than the danger to life resulting from insufficient fire protection, as is shown by compari-

son of the life loss by fire and life loss by disease caused by faulty fire service connections.

This method of safeguarding the public water system, now known as the double F. M. check valve method, was first brought to public attention at a convention of the National Fire Protection Association, May 18, 1910, and at about the same time at a meeting of the New England Water Works Association in Hartford.

F. M. check valves installed. Equipments of this kind have been made in increasing numbers yearly at many of the highest class manufacturing plants in the United States and Canada, until there are now over five hundred such equipments in use. About 75 per cent of these are in New England States, about 17 per cent in New York State and the remainder scattered through the western and southern states, with a few in Canada.

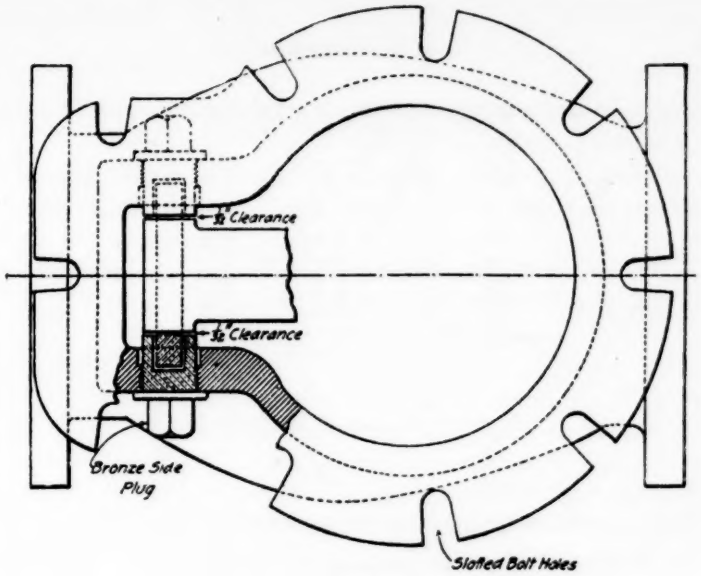
The installation of these equipments has been brought about in many cases by the desire of the property owner to provide the most efficient form of safeguard, in other cases by general orders of local water boards, in some cases by direct recommendation of state health officers and in some by the requirement of a state law.

The principle of operation of these check valves is the same as with any swing check valve containing a clapper hinged above and closing against an inclined seat by its own weight plus the excess pressure from the private fire system.

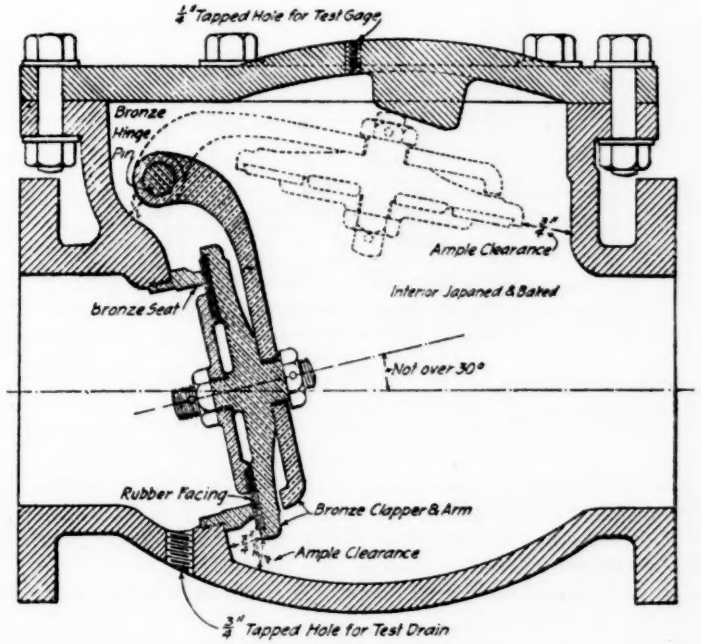
The essential *improvements in construction* are the very wide clearance between the edge of the clapper and the inside of the body; the use of bronze for the seat ring, holding ring, disc, stud, arm, pin and bushings; the use of a medium soft rubber ring closing on a brass seat, and the body design permitting the clapper to swing entirely out of the body for internal inspection by the removal of the cover plate without further disassembling. See figure 1.

The essential *improvements in installation and maintenance* are their accessibility within a frost-proof pit and the resulting facility in determining their condition at any time by means of test drains and gages or by internal inspection. See figure 2.

It is important that no water be used for other purposes than fire or test, through the connections protected by this equipment. If other uses must be provided for, such as drinking or industrial use, such water should be taken from the public supply through an entirely independent connection and a separate system of piping within the property.



PLAN



SECTIONAL ELEVATION

FIG. 1. TYPICAL GENERAL DESIGN OF SPECIAL TYPE OF F. M. FIRE SERVICE CHECK VALVE

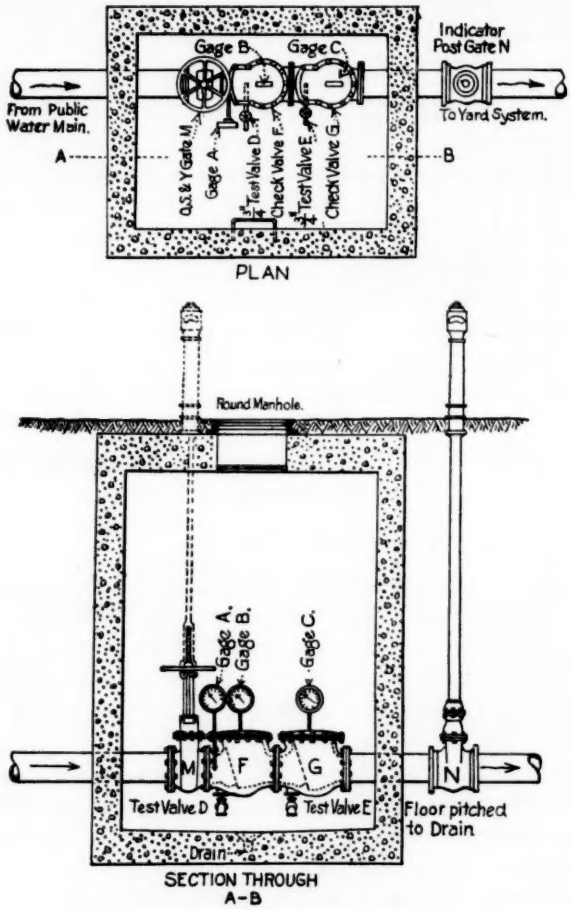


FIG. 2. FIRE SERVICE CONNECTION USING TWO SPECIAL "TYPE F.," CHECK M VALVES

Specifications under which these special check valves are made require the seat ring, disk, holding ring and screws, disk stud, arm, hinge pin and bushings to be of bronze, disk to be faced with medium hard rubber, and liberal clearances left around clapper and arm in all positions.

Normal condition of valves is for gates *M* and *N* to be open and test valves *D* and *E* to be shut.

Method of testing is to open test valve *D* to blow out any sediment that may have accumulated in test valve or connecting pipe, and then close. Close gate *M* and open test valve *D*. If pressure falls at gage *A* and pressure at gage *B* holds after decreasing slightly, check *F* is tight. While test valve *D* remains

A *typical arrangement* for fire service of this kind and an independent domestic service having a dual supply is shown in figure 3. It will be seen that the public and private waters are separated in the

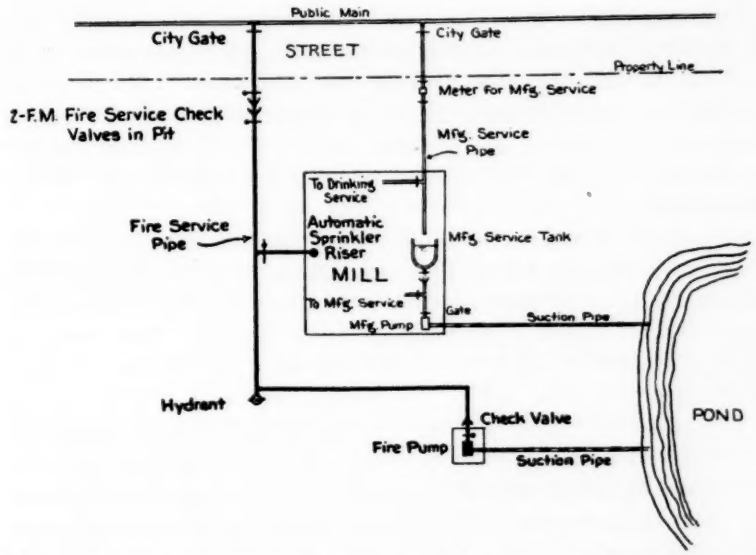


FIG. 3. TYPICAL ARRANGEMENT FOR FIRE SERVICE AND MANUFACTURING SERVICE CONNECTIONS

fire system by the F. M. check valves and in the domestic system by breaking the line supplying the public water at a point above a service tank.

Under *normal conditions* of ordinary practice the water from the public system will pass freely into the private fire system which is

open and pressure at gage *A* stands at zero, open test valve *E*. If pressure at gage *B* falls to zero and flow from test valve *E* ceases, check *G* is tight. *Caution.*—Immediately at close of test see that gates *M* and *N* are open. It is important that the protection be promptly restored.

About once a year inspect check valves and thoroughly clean whole interior. To facilitate removing check valve bonnet, pack with $\frac{1}{8}$-inch sheet rubber packing faced with machine oil and graphite, and grease bolts with heavy oil and graphite.

Size of pit, etc., will vary with different sizes of valves and local conditions, but in general the pit should not be smaller than about 4 feet 6 inches by 5 feet by 6 feet deep. Pit to be water tight when in wet soil and properly drained when in dry soil.

therefore filled with this water so both systems are under the same pressure day after day The check valve clappers need never be subjected to higher pressure than this, excepting in case of fire when the private pressure may be raised by the pump or the public pressure may be lowered by draft from the street hydrants.

If through defect or neglect both checks should be in leaking condition when this variation of pressure occurs, all the clean or public water in the private system between the pump and the checks would have to be expelled before the pump water could reach the public mains and the rate of this displacement would depend on the size of the leak and the difference of pressure between the public and private systems.

Probability of leakage. Not only has this combination of conditions never yet been known to occur, but the quarterly leakage tests and yearly internal examinations made on about 500 such installations of F. M. check valves during the recent years have failed to disclose a condition of the valves where such an occurrence would be at all likely.

This excellent record has brought this safeguard well through its experimental stage to a point where official recognition has now been given by progressive public bodies to the extent of recommending or requiring its use as a necessary improvement in safeguarding the water supply.

Faults to avoid. Caution is necessary in specifying for these installations. One common fault to be avoided is the use of commercial check valves without good clearances and with easily corrodible moving parts. Sometimes the testing connections are omitted and sometimes the pits are improperly drained so they are not easily accessible. So important a device should be installed in accordance with specifications agreed to by the water department having control. Figure 2 shows what has proved to be a thoroughly practical arrangement.

Tracing contamination. Regarding the cases of contamination occasionally reported in connection with this subject, it is usually found when the trouble has been definitely traced to its source, that the fault is most often with the dual connection to the private industrial systems and not from fire service. This is apparently because cross-connections of small pipes within a building can be readily made and easily hidden, they may be under pressure several hours a day, often this supply from the public system has no control

but a hand-operated gate, and often the water department has no definitely enforced rules governing the use of its water.

A few cases have been traced to the use of drinking water taken from a fire system. This condition should never be tolerated.

One case which was recently given much publicity in engineering journals and reported fully in proceedings of this society was traced to a cross-connection between two industrial systems within the same plant. Cases like this have sometimes been used, though improperly, as an argument against the principle of using combination supplies for protection against fire.

The cases where trouble really was traced to the fire service connections were mostly before 1910 and these were the starting points for improvements which have resulted in the equipment as it stands today.

Loss of life. Reference has already been made to the comparative danger of the contamination of the water supply and of loss of life due to insufficient fire protection, with the statement that the greater is from the latter. Not only is this the opinion of many sanitary engineers who have made a study of this question, but the fact is demonstrated by the absence of any known case of contamination having been traced to connections where the F. M. safeguard is used, in contrast with the great loss of lives where adequate fire protection was not provided.

The following list of such fires, although very incomplete, will emphasize the need of better fire protection:

	Lives lost
1908, Collinwood, Cleveland, Ohio	160
1913, Clothing Factory, Binghamton, N. Y.	35
1913, Asche Building (Factory) New York	147
1915, Parochial School, Peabody, Mass.	21
1915, Candy Factory, Brooklyn, N. Y.	12
1915, Paper Box Factory, Pittsburgh, Pa.	13
1918, Button Factory, Newark, N. J.	11

Cases like these would be fewer with greater encouragement of sprinkler protection.

In contrast to this partial record for unprotected properties is the security to life obtained in thoroughly sprinklered factories.

At a meeting of the New England Water Works Association in December, 1915, at Hartford, the statement was made by Mr. H. O. Lacount, Engineer of the Factory Mutual Fire Insurance Companies, that

In approximately three thousand mills scattered all over the country and insuredin the Mutual Companies, and which are very largely under sprinkler protection, during thirty-five years only five lives have been lost by fire, and these factories are occupied every day by about one and one-half million people.

F. M. Checks meet requirements of American Water Works Association report. In 1919 the American Water Works Association Committee on Private Fire Protection Service, Mr. Nicholas Hill, Jr., Chairman, presented at the Buffalo convention the most complete report on this subject that has ever been produced. The four lines of fine print on page 37 of that report (page 715 of journal for November, 1919) state concisely the conditions which should be obtained on all fire service connections and which are now being obtained where the F. M. check valves, properly installed and maintained, are used. This suggested rule is quoted as follows:

No fire protection system having an independent water supply which is unsafe for drinking shall be connected with the public supply mains, unless such connection is so equipped as to positively prevent the flow of water from the piping to the public system.

Suggested fundamental rules. In closing, it can be safely stated that long experience in dealing with water works matters with reference to automatic sprinkler protection has shown that practically all the troubles and questions that beset the up-to-date water works operator may be successfully met by the faithful application of the three following fundamental rules, readily understood with the aid of figure 3.

(a) All private pipe systems from which water is used for manufacturing or domestic purposes should be entirely independent of private pipe systems used for fire service.

(b) No connection should be maintained through which water of unapproved quality can be discharged to the pipes of the public water system from any private auxiliary system.

(c) Every fire service connection from the public mains where the secondary supply is of unapproved quality should be provided with two specially constructed check valves, so installed as to permit ready inspection and subject to the approval of the water department.

The extent of recognition and the events leading up to the present extensive use of this safeguard are briefly outlined as follows:

Reasons for the invention. To avoid defects discovered over a long period of years prior to 1910.

First public references. 1910, April, New England Water Works Association, Hartford, by E. V. French, Fire Protection Engineer for the Factory Mutual Insurance Companies. 1910, May, National Fire Protection Association, Chicago Convention, by H. O. Lacount, Engineer Factory Mutual Insurance Companies.

Distribution of present installations. In 1920 a total of about 520, with 75 per cent in New England and 17 per cent in New York state. The states having more than 12 installations up to 1921 were: Massachusetts, 273; Connecticut, 58; New York, 86; New Jersey, 18; Ohio, 16; Maine, 15.

Early important installations. 1908–1909, Hartford, Conn., 14 connections; 1909–1912, Auburn, N. Y., 20 connections; 1909–1913, New Bedford, Mass., 33 connections; later than 1913, New Bedford, Mass., 42 connections; 1916, Passaic, N. J., 10 connections; 1917–1918, Fall River Mass., 92 connections; 1917–1918, Utica, N. Y., 22 connections.

Official Recognition.—New York. Accepted as "Sufficient and satisfactory safeguard" by New York State Commissioner of Health, April 29, 1918. Tentatively approved by Chief Engineer, New York State Department of Health, April 16, 1918, with favorable comment on the Auburn, N. Y., installations.

New Hampshire. Section 3, Chapter 205, Law of 1913, as amended in 1919, relating to emergency intakes and factory connections states, "Every valve, gate or other device for controlling or preventing the inflow of water of such unapproved character to the public supply pipe system must be of such construction as to permit of efficient inspection, and testing, and an actual test thereof shall be made not less than twice annually by the individual, corporation or association furnishing water to the public."

This is further interpreted by a circular issued by the Secretary of the State as follows:

> It is, therefore, required that in the case of every factory connection involving an unapproved source, there shall be installed a modern double check system, of the type generally known as the "Factory Mutual" fire service connection.

Instances of Recommendation of acceptance in special cases.—New Jersey. State Board of Health, 1915, investigated and recommended this arrangement of "double check valves of improved construction" to a local water company taking from a large distributing system serving many communities.

Health Departments of the States of Pennsylvania, Ohio, Indiana and Michigan, and also the United States Shipping Board.

Important instances of its requirement by local water boards.—New Bedford, Mass. Water Department allows no fire service connection unless it is equipped with the standard arrangement of F. M. check valves. All are so equipped. Secondary supplies mostly from salt water.

Fall River, Mass. 1917 Watuppa Water Board following the revised ordinances of the city required changing all the old single check valves for standard arrangement of F. M. check valves and all are now so equipped. Secondary supplies are from salt water and open ponds.

Auburn, N. Y. Water Department allows no fire service connections without this safeguard.

Utica, N. Y. Ordinance requires complete severance or use of the double check valves.

Waterbury, Conn., is now equipping all factory fire service connections with this safeguard, a total of about 46.

Result of ten years experience of the Inspection Department of the Associated Factory Mutual Fire Insurance Companies.—No case of contamination of a public water supply has yet been traced to the failure of the F. M. check valves. No case of leakage past both checks at once has been reported where the rules for maintenance have been observed.

EFFECTIVE DILUTION AS A POLLUTION UNIT[1]

By Wm. Firth Wells[2]

With the American practice of discharging all wastes into the natural surface waters, and the customary use of the same surface waters as a source of domestic water supply, it is essential to have accurate means of determining the permissible concentration of such wastes in waters used for various purposes. Sanitarians have adopted certain empirical criteria which are correlated with bacteriological tests for sewage organisms in determining the quality of the water. Given the daily wastes from one person in a gallon of water as the initial unit of extreme contamination, the problem reduces to the dilution of this material which shall be required before the resulting mixture may be accepted in a water supply. In a rough degree the following general proportions have been found to hold true. A dilution of one hundred times gives ordinary sewage. A dilution of sewage one hundred times gives a highly polluted river water. A dilution of a hundred times again gives a polluted river water acceptable for filtration purposes. A dilution again of a hundred times gives a water which may be acceptable for drinking purposes and another dilution of one hundred times gives a water exceeding in all tests the highest unit demanded of a water supply.

In the investigation of the dilution required in international boundary waters, Prof. E. B. Phelps developed standards of dilution according to accepted sanitary practice. Not only did he determine the dilution necessary to eliminate danger from sewage infection,

[1] The Publication Committee has accepted this contribution because it opens up an interesting field of speculation, but this acceptance is not to be taken as an endorsement of the author's apparent position that dilution of polluted water and its treatment by storage, sedimentation, filtration and sterilization until the bacterial counts from the two treatments are alike, are practical hygienic equivalents. Comments on the paper by a member of the committee appear on page 270 of this issue. Further discussion of it is invited and should be sent to the Editor.

[2] Biologist and Sanitarian, New York State Conservation Commission, Albany, N. Y.

but he introduced a conception which has proven very valuable in studying the relation of sewage contamination to water supply. He showed that whereas direct dilution is a primary means and measure of the elimination of the effect of pollution, other processes by reducing the infectivity of sewage may be stated in terms of "effective dilution." The ordinary water carriage sewerage system in American cities effects a dilution of a hundred gallons per capita, which constitutes the average American sewage. Simple processes of sewage treatment, such as screening and chlorination, eliminate approximately 90 per cent of the sewage organisms and, therefore, can be considered to have the same effect as, or an "effective dilution" of, ten times. Complete sewage disposal should yield a purification of 99 per cent and, therefore, can be considered to have an "effective dilution" of one hundred times. Likewise, in the treatment of drinking waters complete purification should remove 99 per cent of sewage organisms and, therefore, may be considered to have an "effective dilution" of one hundred times; while simpler processes may yield 90 per cent removal which is an "effective dilution" of ten times.

It is thus seen that the dilution of the daily wastes per capita in one gallon of water to one part in ten billion of water would be considered by all sanitarians as to be beyond any reasonable probability of infection as a drinking water. A dilution of one part in a hundred million still becomes a tolerable allowance by lenient water supply standards. The dilution of one part in a million gives a water which can be suitably treated by present methods of purification to yield a satisfactory water supply. Since sewage has an "effective dilution" of one part in a hundred, and sewage treatment with an "effective dilution of one part in a hundred yields an effluent of a total "effective dilution" of one part in ten thousand, it may be seen that there remains an interval between the limits of sewage treatment and the requirements for water purification, of an "effective dilution" of one part in a hundred which must be supplied by the natural waters. This "effective dilution" must be considered the minimum requirement of river purification.

The bacterial purification of streams thus becomes a link in the problem, and it is necessary to determine the rate of disappearance of sewage organisms in a stream in order to determine the relation between time and "effective dilution." This problem was carefully worked out in the investigation of the Potomac River and a series of

more than ten thousand analyses made throughout the year and corrected for various factors gave a death rate constant for B. coli, such that a 7.5-day[3] storage interval can be allowed as equivalent to an "effective dilution" of ten times. Within the zone of river purification this constant may be accepted as rigid, and for purposes of engineering calculations it may be considered a theoretical condition which may be extended into the zone of sewage treatment and water purification. In actual practice sanitarians have arrived at a time factor for storage reservoirs which may be considered the safe equivalent of efficient water purification, in which various considerations are involved other than the natural death rate of sewage organisms in the water. Likewise, in extending the practical conception of bacterial death rate within the sewage zone itself, other factors such as septic action are involved and here the relation between "effective dilution" and time is also subject to opinion. In the one case the medium itself is an interfering factor and in the other case the change either in the resistance of the organisms or factors of safety with regards to re-infection cause us to deviate in practice from results which the extension of the theoretical curve would indicate.

It thus becomes apparent that the several means by which the effect of original wastes may be eliminated, may be all stated in terms of dilution and when so stated may be given "effective dilution" equivalents. The zone of sewage is direct dilution; sewage treatment may be stated in terms of dilution; river purification or the natural death rate of sewage organisms may be considered as the relation between time and "effective dilution;" and water puri-

[3] The time interval allowance of 7.5 days for each "effective dilution" representing 90 per cent removal of B. coli is quite liberal. From the Potomac River curve (Hygienic Laboratory Bull. 104) the average "effective dilution" for the first six days was 0.16, while in the next 5 days it averaged 0.13 "effective dilution," and dropped to an average of 0.08 "effective dilution" for the next 4 days. Since reinfection and other factors tend to reduce the value it is more probable that a period of six days or less is equal to one "effective dilution" or a B. coli reduction of 90 per cent.

In fact, as a theoretical death rate constant, the author, from experience and knowledge of the factors involved in the Potomac River Investigation, would prefer to assume a period of five days as equivalent to one "effective dilution," or the dilution of one part in ten, or a reduction of 90 per cent. This shows the immense importance of the time factor in river purification, but a sufficiently careful analysis of experience supports the conclusion.

fication and storage may also be stated in terms of "effective dilution." In order to present these factors in a consistent manner figure 1 has been prepared. The dilution unit has been taken as one part in ten, which corresponds to a unit previously described as "dilution positive." It may be seen from a study of the figure that this unit of "effective dilution" is a reasonable and convenient one in which to consider the various stages in which the wastes are transformed or absorbed by methods of removal or elimination into drinking water. Not only is it a convenient scale on which to consider the results and steps, but it is also a convenient scale on which

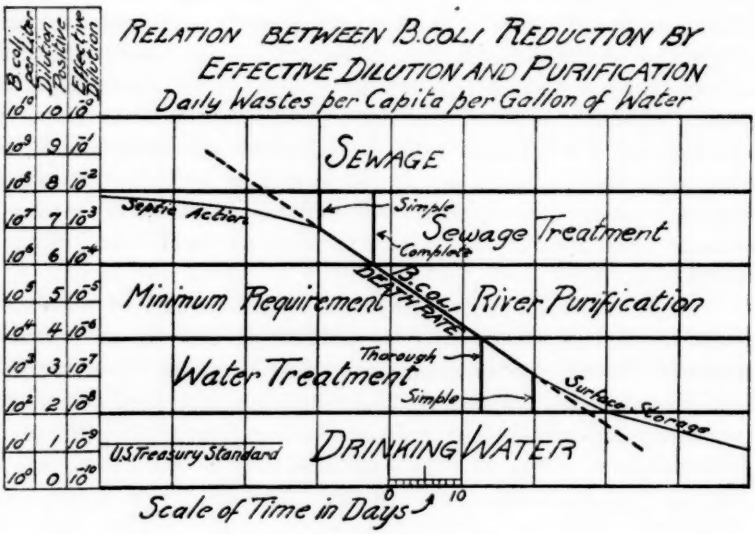


FIG. 1

to classify and compare the actual media with which sanitarians and engineers constantly are dealing. A water, for instance, which has an "effective dilution" equivalent to a "dilution positive" of five, may be considered one which by diluting ten times or by storage of 7.5 days may be suitable for efficient filtration to produce a drinking water; or by 15 days' storage, or a dilution of ten times plus 7.5 days' storage may be treated simply to produce a drinking water; or which with a dilution of ten times may be rendered suitable in storage reservoirs after thirty days storage for drinking water. Furthermore, this condition may be arrived at by diluting the per

capita daily waste per gallon of water one hundred thousand times; or by diluting a completely treated sewage ten times; or by the storage for 7.5 days of a simply treated sewage which has been diluted ten times, etc. In other words, the units are interchangeable, and if the sanitarian has given an "effective dilution" equivalent to any "dilution positive" on the scale, it is a simple matter for him to determine by its location on the scale the nature of the medium with which he has to deal and the requirements necessary to produce a drinking water. Since the units are interchangeable, a very simple system is available for comparison and calculation.

Having discussed the effective dilution equivalent of water and sewage with which the engineer is concerned, it is desirable to show how they are related to the determinations of the laboratory. The bacteriologist in making his tests for B. coli, which are taken as the basis of sanitary examination, does nothing more than determine the absolute dilution necessary to eliminate the presence of this organism from his tubes. It is interesting to note that the actual steps in which he customarily makes these dilutions are precisely the same as the scale given on the chart; in fact, the "dilution positive" is a term developed because of simplicity and certain theoretical advantages in which the bacteriologist can give a statement of the results of his finding exactly as they are determined. It now appears that these statements are directly parallel to terms of "effective dilution" which the engineer uses. In other words, the conception "number of B. coli per cubic centimeter" is not at all necessary or desirable, and but leads to confusion which is too apparent when the engineer and the bacteriologist try to exchange information. If the bacteriologist merely states that he has diluted a given sample a given number of times and obtained a given "dilution positive" the engineer without puzzling over the hypothetical significance of B. coli knows exactly where on his scale of action the result is located, and the processes which will bring about such a result, and the necessary factors required to produce any condition in which he is interested. Thus the "effective dilution" of the engineer and the "dilution positive" of the bacteriologist are parallel units which make the results of one immediately available to the other.

Without going into the mathematical advantages of the results obtained by averaging and computing "dilution positives" directly, or the simplicity which it means to the laboratory man and the engi-

neer, it may be stated for those who have any desire to arrive at an expression of the number of B. coli per liter that this result may be obtained as the antilogarithm of the "dilution positive." The reason for this is evident since the "dilution positive," because of the nature of the scale, is the logarithm of the number of B. coli per liter. Moreover, since the "average dilution positive" is the average logarithm it is the logarithm of the geometrical mean number of B. coli per liter. The theoretical reason why the geometrical mean is preferable to the arithmetical mean in the expression of B. coli results arises from the geometrical nature of the distribution of such results, and its practical advantages have been explained elsewhere.

If the bacteriologist expresses his result as the "dilution positive" in which he actually determines B. coli, and the engineer uses the same unit as an equivalent of the "effective dilution" of the daily wastes of one person in a gallon of water, each has an interchangeable unit which will simplify the expression of problems of sanitation and sanitary engineering.

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SIGNIFICANCE OF HYDROGEN-ION CONCENTRATION IN DRINKING WATER AND PARTICULARLY FOR THE BUSINESS OF WATER SUPPLY[1]

By A. Massink[2] and J. A. Heymann[3]

PART I. GENERAL REVIEW OF HYDROGEN-ION SIGNIFICANCE WITH SOME DATA FROM OUR WATER SUPPLIES (MASSINK)

As several observers have already pointed out, Tillmans, by his introduction of the concept "aggressive CO_2," has had the chief share in bringing order and insight into this subject. In his book "The Chemical Examination of Water and Sewage" (1915) he has explained this clearly. He has recently, while this report was in the press, given an extension in which he has especially considered the hydrogen-ion concentration of water, a logical sequence of his earlier work. He emphasizes the significance of hydrogen-ion concentration for practical purposes.

It may be stated at once that for corrosive action of a water-supply the hydrogen-ion concentration is not the only factor—the oxygen, amongst others, plays a part. Tillmans' writings on aggressive CO_2 refer particularly to the reaction with $CaCO_3$ which proceeds as follows:

$$CO_2 + H_2O + CaCO_3 \rightarrow Ca(HCO_3)_2$$

until equilibrium is attained.

[1] This paper was sent to Abel Wolman by Dr. Massink after he had read the former's paper on "Coöperative Research in Water Purification" presented at the Montreal Convention. The paper is in two parts, the first by Dr. Massink and the second by Dr. Heymann. Both were written in Dutch and were translated into English by Frank Hannan, chemist of the Toronto Water filtration works; the translation was prepared for publication by Mr. Wolman. Discussion of this paper is desired and should be sent to the Editor. The Publication Committee feels that important papers on water supply, even though highly technical, should appear in the JOURNAL, as the chief American repository of valuable information on water supply in all its aspects.

[2] Of the Central Laboratory of Holland.

[3] Vogelensang, Holland.

If the CO_2 content of the water is below the equilibrium value, then the reaction goes in the other direction:

$$Ca\ (HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$$

also to attainment of the equilibrium.

With respect therefore to the "aggressive CO_2" there are three cases possible: 1, The CO_2 concentration may be exactly that which equilibrium demands. 2, The CO_2 concentration may be greater (aggressive). 3, The CO_2 concentration may be less (reverse of aggressive).

In water supply, we are principally concerned with corrosive action on metals, in which the oxygen also plays a considerable part, inasmuch as when both a high oxygen concentration and aggressive CO_2 are present together, we may expect more corrosion than from aggressive CO_2 only. When we estimate for a given water the aggressive CO_2 according to Tillmans, we are estimating the CO_2 which acts on $CaCO_3$; for other materials other considerations must be taken in account.

It also is clear from the basic notion of aggressive CO_2 that it is not the hydrogen-ion concentration alone, but this taken in conjunction with the other constituents, which is of significance. One cannot, for example, say that a water with a hydrogen-ion concentration below this or that value is "aggressive" and above it, "not aggressive." For instance it might be imagined that pH = 7, corresponding to exact neutrality would be such a limit. But this is not so. The free CO_2 and HCO_3^- ion concentration must both be taken into account. Indeed, it is a well-known rule that a soft water becomes aggressive more readily than a hard.

HCO_3^-	FREE CO_2	HYDROGEN-ION CONCENTRATION	HCO_3^-	FREE CO_2	HYDROGEN-ION CONCENTRATION
mgm.	*mgm.*		*mgm.*	*mgm.*	
14–111	0–1.75	8.3–8.1	263.0	20.75	7.48
125.0	2.4	8.1	277.0	25.0	7.43
139.0	3.0	8.05	291.0	29.5	7.38
152.0	3.9	7.96	305.0	36.0	7.31
166.0	4.8	7.92	319.0	40.75	7.28
180.0	6.0	7.85	333.0	47.0	7.23
194.0	7.5	7.8	347.0	54.0	7.19
208.0	9.25	7.75	360.0	61.0	7.16
222.0	11.5	7.66	374.0	68.5	7.13
236.0	14.1	7.6	388.0	76.4	7.09
249.5	17.2	7.54	402.0	85.0	7.04

In Tillman's new publication above referred to, he gives free CO_2 and HCO_3^- concentrations which are in equilibrium with one another and the corresponding hydrogen-ion values. See table on page 240.

We do not need to follow this table further because, in drinking water at least, values for free CO_2 never reach even as high as those we have given.

An example will best serve to illustrate the use of these figures—Say a certain sample of drinking water is found to contain 300 mgm. HCO_3^- and 10 mgm. free CO_2, both very normal values. Seeing that 34 mgm. (more or less) of free CO_2 may occur in with 300 mgm, HCO_3^-, according to the table, before there can be any question of aggressive CO_2, this water cannot be aggressive, and the hydrogen-ion value must be greater than 7.34 which would be the table value for equilibrium. The calculation, in fact, following the well known formula:

$$[H^+] = K. \frac{[CO_2^-]}{[HCO_3^-]} \text{ and taking K. } = 3.04 \times 10^{-7} \text{ gives:}$$

$$[H^+] = 3.04 \times 10^{-7} \times \frac{2.27 \times 10^{-4}}{4.92 \times 10^{-3}} = 1.4 \times 10^{-8} = 10^{-7.85} \therefore \text{pH} = 7.85.$$

One may also proceed in another manner. Let the hydrogen-ion value be determined by one of the methods herein after given, or approximately estimated, and the HCO_3^- (or the free CO_2^-) content also determined; then one can see from the table whether the hydrogen-ion concentration corresponding to the value found for the HCO_3^- (or the free CO_2) is lower (aggressive) or higher (not aggressive).

The latter seems to me in general preferable for a HCO_3^- determination (titration with $\frac{N}{10}$ acid in presence of methyl orange) is simple to effect (much more practical than the apparently equally simple but in fact demanding much experience CO_2 determination) and a tolerably exact colorimetric hydrogen-ion estimation can easily be made. Fairly accurate conclusions as to presence or absence of aggressivity can be drawn.

From the table as given the following conclusions can also be drawn:

The table is continued almost to a hydrogen-ion value of 7. This corresponds to a bicarbonate hardness of $\frac{402}{61} \times 2.8 - 18.5°$ (German degrees of hardness) on the understanding that there is no question of water containing alkali bicarbonate. As a rule the temporary

hardness of tap water is considerably lower. Thus if a tap-water has a hydrogen-ion value of 7, it is almost certainly aggressive. Colorimetrically we may express this as follows: such water will react acid or at least very near the acid limit, with neutral red. The range of this indicator runs from pH = 6.8 (acid) to pH = 8 (alkaline). An acid reaction toward neutral red is thus an indication that the water is almost certainly aggressive. The matter of aggressivity, however, depends on the composition. Thus a very soft water (moor-water) with a low HCO_3^- content will be much more aggressive than a water with a temporary hardness of 10° (218 mgm. HCO_3).

One cannot, however, reverse this rule: A neutral reaction toward neutral red (about pH = 7.5) can very well be exhibited by an aggressive water: as one can readily see from the above.

From the examples given it should be clear, as we have already stated, that for the hydrogen-ion concentration of a water the free CO_2 and the HCO_3-ion play an important part. Just as in physiological fluids the hydrogen-ion concentration is regulated by the so-called "buffer" substances, these are also supplied by nature in water, and chiefly in the form of the bicarbonates. The poorer, then, a water is in these (moor-waters), the more readily is the hydrogen-ion concentration affected by varying influences (chiefly in this case CO_2); the water can thus become aggressive. Of this we shall see examples later in the data of our water supplies.

Naturally there is a very intimate connection between the composition (especially buffer-content, pH, etc.) of the soil and of the water that is, or has been, directly in contact with it.

Before leaving Tillman's table we should also mention the following:

In an article "On the connection between certain concentrations in the equilibrium between aqueous carbonic acid and $CaCO_3$," two curves (A) and (B) are traced for the relation of $[H^+]$ to $[HCO_3^-]$:

$$(A) \quad [H^+] = 2.29 \times 10^{-3} [HCO_3^-]^2$$
$$(B) \quad [H^+] = 2.07 \times 10^{-3} [HCO_3^-]^2$$

For brevity, refer to the article in question for the deduction of the curves. The table, already given, is graphically presented in figure 1. The continuous line shows the values deduced according to equation (A). The broken line represents Tillmans' table, and differs but slightly from the values obtained by Auerbach's equation (B),

which would run parallel to the continuous curve given and slightly above it.

Just as one has, following Tillmans, a criterion with respect to aggressive CO_2 by comparison of the actual concentration of free CO_2 with that concentration given by him as corresponding to the known HCO_3^- concentration, so one can also from the figure form an opinion of the aggressivity of the water, when one knows the pH and the HCO_3^- concentration. If with a given HCO_3^- content the pH is lower than that given by the continuous curve (theoretical curve) or the broken curve (Tillmans' empirical curve), then that

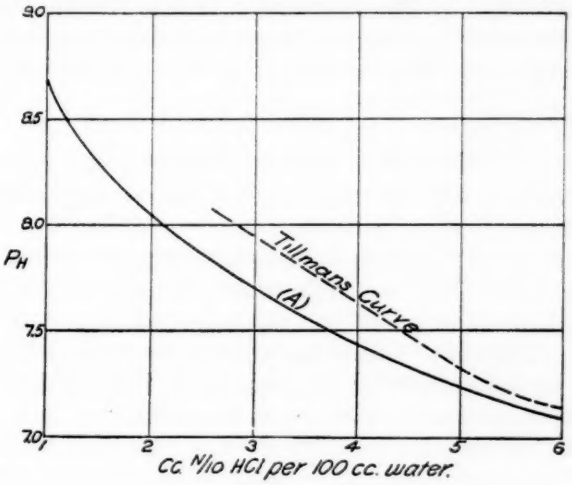

FIG. 1

water will be aggressive; if higher, not aggressive. Consequently in the first case marble will be dissolved; in the second $CaCO_3$ will be deposited.

We shall adopt for this purpose the empirical curve of Tillmans; but it must not be lost sight of that this curve, which represents the results of his experiments with $CaCO_3$, CO_2, and H_2O, cannot at the same time hold good with absolute exactness for all kinds of tap waters. In a certain sense it is also more prudent to take his curve than the theoretical, as it will decide for aggressivity rather earlier.

Before proceeding to the discussion of the data which the yearly examination of our water-supplies has furnished, a point deserving of closer consideration is: in what respect do the various properties of drinking-water depend on the pH?

Especially is an aggressive character imparted to the water by too high pH. Different phenomena may result herefrom.

1. The water-mains and other objects may be attacked. If this occurs with lead pipes, a lead-content dangerous to health may ensue; this case is thus chiefly of hygienic importance. We cannot further consider it here, because it needs an extensive independent research.

In case of pipes of other material the matter is rather of technical importance. One important consequence may be the so-called "re-ironing" by which the results of iron removal are to a certain extent rendered nugatory. The aggressive CO_2 first forms $Fe(HCO_3)_2$ (ferrous bicarbonate), which can remain in solution so long as the oxygen present is insufficient for completion of the following reaction:

$$4\,Fe\,(HCO_3)_2 + O_2 + 2H_2O = 4\,Fe\,(OH)_3 + 8\,CO_2$$

The CO_2 is thus reproduced. This last reaction is the regular iron-removal reaction which naturally takes place in the iron-removal installation, and *not* in the mains.

A case of this "re-ironing" came under my notice in a private water-supply in S. Limburg. The water contained about 40 mgm. CO_2 and about 25 mgm. HCO_3^- and was "de-ironed" in a closed apparatus. After the "de-ironing" the water carried about equal quantities of CO_2 and HCO_3^- and gave rise to iron solution from the mains. Acid neutralization was here the remedy indicated.

Sometimes cases occur in which the water becomes more acid on boiling, as appears occasionally to be the case with water from the Uden reservoir. Such water is of course absolutely unsuitable for any kind of industrial use, notwithstanding its softness, which in water otherwise suitable is a desirable quality in boiler-feed water. This phenomenon does not seem to have cropped up in any of our public supplies. On the contrary in the vast majority of cases the water becomes alkaline to phenolphthalein on boiling, so that this may be said to be a favorable showing as judged by this "boiling test." If we agree to call this result by the boiling test "negative," then a positive result (e. g., Uden) is to be regarded as unfavorable. The cause for this acidification on boiling cannot yet be satisfactorily explained. Probably after some time it will be cleared up from analytical data.

2. Greater difficulty in iron-removal. The Limburg water above mentioned was very difficult to de-iron, especially in a closed apparatus.

The water of the Coevorden supply, which shows considerable similarity to the above, gives rise to the same difficulties. The raw water will remain absolutely clear for days, even when left in a bottle in contact with air, and only slowly develops turbidity. Probably the very high SO_4^{--} concentration plays a considerable part in this. One is dealing, as a matter of fact, with a solution which approximates closely to a dilute $FeSO_4$ solution and is more stable than a $Fe(HCO_3)_2$ solution.

A high concentration of Cl^- or SO_4^{--} together with a low concentration of HCO_3^- has thus an unfavorable influence on the iron removal, which is still more pronounced when CO_2 is also present.

Occurrences of artesian water have come under the author's notice which are not suitable for drinking, which showed at first an alkaline reaction to methyl orange but contained large quantities of CO_2, Cl^- and SO_4^{--} and much ferrous iron in solution and which, by degrees, showed a steadily increasing acidity toward methyl orange, due to formation of basic ferric compound (chloride and sulphate and free mineral acid.) The disappearance of Fe^{++} and the increase in Fe^{+++} could be simultaneously observed.

This case is, of course, a very extreme one such as one cannot often meet in drinking water; the S. Limburg and Coevorden waters are weak analogies.

Already in 1911 Baskerville and Stevenson showed that Fe in acid and neutral solution at room temperatures is very slowly oxidized in the absence of catalyst (platinised asbestos), but rapidly, on the contrary, in alkaline solution. (Jour. Amer. Soc. Chem., 1911, 1104.)

Hence it is that soft iron waters with relatively high CO_2 content are difficult to free from iron.

3. The significance of hydrogen-ion concentration in drinking water seems also to extend to a department which is of less concern to the chemist than to the physician, namely mineral waters.

4. Also in the chemical analysis of water there are instances of the hydrogen ion concentration being of significance. Thus, for example, in the decolorization of deep brown humus containing waters ("veenstreken") previous to analysis, by means of a suspension of $Fe(OH)_3$, the decolorizing action of which increases when the HCO_3 content of the water has been reduced by addition of acid.

Further the precipitation of silicic acid from drinking water by means of soda and alum, where the reaction toward phenolphthalein

is of importance. These examples have not yet been treated of in close connection with the pH, but all probably depend on this connection.

Data respecting the hydrogen-ion concentration of our water supplies

The yearly examination of the water of the Netherland water-supplies by the Central Laboratory has yielded considerable material for the preparation of this report. In 1919 all the pumping stations were visited and determinations of free CO_2 and HCO_3^- (amongst others) carried out on the spot; further the hydrogen-ion concentration was colorimetrically estimated, in which also the freshly pumped raw water was compared with the filtered water before it was "purified" by one or the other process. Also the Heyer marble test was made on the spot on the filtered water. As soon as possible after arrival at the Central Laboratory the hydrogen-ion concentration of the raw and filtered water was determined. During 1919 this was done by the well known Sörensen colorimetric method. Naturally there are certain disadvantages inseparable from this way of working; for example the influence of the alkali of the glass became noticeable during the storage of the water in the bottles (3-litre, nearly or quite full), also Kahlbaum's primary and secondary phosphates were not to be obtained, so that these had to be made up from phosphoric acid solutions of titrated strength and NaOH solution. The solutions specified by Michaelis were employed. Neutral red and methyl red were chiefly used as indicators; alpha-naphthol phthalein to a less extent. This latter indicator was found to give in general too low a value for hydrogen-ion concentration, which is in agreement with Sörensen's results unless the "salt error" of the indicator is taken into account. As this indicator is suited for the range between neutral red and phenolphthalein (pH 8–8.3) the values in this range could not be determined with thorough exactness.

It is true that neutral red does not always give even approximate results. Thus, for example, it was remarked in the early part of 1920 that while two samples gave the same result electrometrically, the tints with neutral red differed—so that the water of greater salinity appeared more acid. This too is in line with Sörensen's experience. Thus one can only regard the colorimetric method as an approximate one, which may or may not be sufficiently accurate

for practical work but does not give absolutely correct values, as indeed is generally known.

The electrometric method just mentioned is, on the other hand, more exact. In 1919 the necessary installation was not complete, so that only in 1920 could work be done with it. The installation used is almost identical with that described by Kolthoff but a calomel electrode with saturated KCl solution was used. The firm Marius sells a round "Schakeltafel" to which the galvanometer is fixed which greatly simplifies the setting up. In calculating the results, use is made of Sörensen's curves to which an "exponential line" for saturated KCl must be added. After taking a reading one has then the hydrogen-ion value required in less than a minute. It was observed that attainment of equilibrium of the hydrogen electrode was slower and the reading less sharp, according as the water is poorer in salinity ("mixture poor in buffer substances").

The phosphate solutions last used in 1919 were examined electrometrically as a control. Equal concentrations of primary and secondary phosphates gave hydrogen-ion concentrations as follows: electrometric, 6.85; Sörensen's figure, 6.81; thus they were in good agreement.

In 1920 as many as possible of the samples examined were tested electrometrically for hydrogen-ion determination, while in 1919, as explained, the colorimetric method was used.

In 1919, moreover, as already mentioned, the marble test was carried out. After the lapse of 3–4 days for very soft waters, and about a week for harder waters, the hydrogen-ion concentration value of the water from which the marble powder had settled out was again determined (colorimetrically; some also calculated from the values found for free CO_2 and HCO_3^-) and the value found compared with that of the filtered water. In this comparison, three cases were possible:

1. After the marble test, pH greater; aggressive water.
2. After the marble test, pH less; non-aggressive water.
3. After the marble test, pH unchanged.

This first case holds for water with aggressive CO_2: the aggressive CO_2 brings $CaCO_3$ into solution in the form of $Ca(HCO_3)_2$, so that, as compared with the filtered water, the CO_2 content is lower and the HCO_3^- content higher, whereby the hydrogen-ion concentration becomes greater.

The second case holds for non-aggressive water in which, accordingly, the free CO_2 content is not enough to retain the alkali-earth bicarbonates in solution. It is not to be imagined that this $CaCO_3$ precipitation occurs rapidly; this takes place very slowly except when a considerable deficiency of CO_2 is found combined with a very high HCO_3^- content (not usual in drinking water).

After the marble test the CO_2 content has become higher and the HCO_3^- content lower:

$$Ca\ (HCO_3)_2 = CaCO_3 + H_2O + CO_2,$$

whereby, therefore, hydrogen-ion concentration becomes lower. This is very frequently the case with drinking waters.

The third case holds for the waters in which there is equilibrium between the CO_2 and the HCO_3^-. Some drinking waters come under this category as being almost in this condition.

In the first case the equilibrium is more readily attained than in the second: this is because the solution of the marble takes place more rapidly than does the $CaCO_3$ precipitation.

The figures embodying the results of the examination of the water supply samples by the Central Laboratory are given in the following table.[4]

The results for the most part relate to the examinations in 1919. As the variations from year to year are not great it was preferred to give the CO_2, HCO_3^-, etc., values for the same year in which the colorimetric pH determinations and the marble tests were made. These results for HCO_3^- and CO_2 can also be obtained from the report which will probably soon be published for the "Vereeniging voor Waterleiding belangen." The electrometric pH determinations were made in 1920. Probably most water supplies show no considerable variation in the pH so that a comparison with 1919 is fairly permissible. The figures for HCO_3 and CO_2, for example, over the various years vary but slightly. Naturally the time which elapses from the taking of the sample is of influence, by which here and there variations of some account appear. As the colorimetric determinations are more numerous than the electrometric, the conclusions, positive or negative as to aggressiveness, were drawn from the former.

The following supplies have certainly aggressive CO_2 (that is both colorimetrically by the marble test, and according to Tillmans' curve):

[4] The tables accompanying Dr. Massink's article were not submitted by Mr. Wolman, as they were numerous and not needed for clarity.

Almelo, Amsterdam (Westwevold), etc., 31 all told; that is about 30 per cent of our supplies.

By far the greater number of these belong to the moor-waters which give a supply with low bicarbonate hardness. There are two surface water supplies among them, Groningen (de Punt) and Leenwarden, in which by alum treatment the bicarbonate hardness is so reduced that aggressive CO_2 has developed.

Also at Hoorn the water has been made aggressive because by the treatment with lime and sulphuric acid the bicarbonate-hardness is considerably reduced. The H_2SO_4 treatment converts the $NaHCO_3$ into Na_2SO_4.

With certainty, a very great certainty, the following are non-aggressive:—Alblasserdam, Alkinaae, etc., all told, 67, or about 65 per cent of our supplies, including among others, the river supplies (excepting Leewarden and Groningen, dePunt), and the dune supplies; in general those supplies with relatively high bicarbonate hardness.

In order to compare the results given by the chemical examination in the Central Laboratory with the results obtained in practice, which could therefore be considered as known to the various water supply operators, a questionnaire was sent to these with the following questions: the resulting answers are given and discussed below:

Question A. Has the presence of aggressive CO_2 been noted in your supply, in the raw or in the filtered water? If so, is this a constant feature?

Question B. How does the aggressive CO_2 manifest itself? What objects are attacked and with what result?

Question C. Is the aggressive CO_2 so troublesome that measures to combat it have been designed or undertaken? If so, what are these measures?

Question D. What has been the result of these measures?

As a result of the questionnaire the following was obtained:

Of the 106 water-supplies, 40 have answered that no evidence of aggressive CO_2 has been observed; 11 have answered that it has been observed; 50 did not answer; a few answered very vaguely. Of the 50 not answering, 22 should, in accordance with the examination which the author made, have had aggressivity to report.

Discussion of results of questionnaire. From the results the following can be inferred:

1. That from about half of the water supplies answers have been received.

2. Of those who have answered and in the sense that manifestations of aggressive CO_2 are positively reported, about 20 per cent report such manifestations.

3. Of those who have not answered, probably 45 per cent would have had such manifestations to report.

A selection from the data obtained from the operators is appended.

Amsterdam (Westerveld): Aggressive CO_2 present all the time. This appears from the analysis and the marble test. In practice this manifests itself by non-formation of a protective coating of $CaCO_3$, so that metals (iron, lead, zinc) are powerfully attacked. Amongst the measures taken against it is the use of tin-coated pipes to prevent lead being taken into solution. This object has been attained.

Apeldoorn: Manifestation of aggressive CO_2 can only be attributed to the organisms in the mains, which deposit as a very firmly adherent coat. Measures against it have not yet been needed or planned. Unfortunately some of the larger mains will have to be repaired.

Deventer: Aggressive CO_2 has been the chief cause of lead appearing in the water. After the inauguration of the closed iron-removal plant, this was the case. There is now an installation to remedy this defect.

Enschede: Aggressive CO_2 is all the time present in the raw water. Pipes of lead or of unprotected iron are of no use. The lead-solvent power of the water is so great that only tin-lined lead pipes can be employed. The aggressive power is greatly reduced by spraying ("rieselen") and the lead solvent action is nearly altogether removed; each case reduced to one-tenth.

Gouda: The raw water (river water, from time to time mixed with pond water) does not attack the iron of the pipes. The filtered water was formerly treated with alum resulting in the pipes being attacked with formation of bumps ("red water"). After the abandonment of the alum treatment these phenomena have disappeared, probably permanently. To remove the aggressive CO_2 a layer of 15 cm. "schelpen" was spread on the slow sand filters, which caused a considerable increase in the filter pressure and had to be rejected.

Den Helder: From some iron being attacked it can be concluded that corrosion is in evidence, but only in the raw water. These manifestations do not occur in the centrifugals nor in the drawn iron mains; they are found on forged-iron articles (stays and bolts of filters). As they do not amount to very much, no measures have been needed to combat them.

Helmond: Rust formation was occasionally noted in the cast-iron mains, which was ascribed to free CO_2. No measures necessary.

Maastricht: The blades of the high-pressure centrifugal pumps, both of bronze and of iron, are very rapidly corroded by the water on the suction side. This was set down to aggressive CO_2. As means to combat it, there have been recommended, first, powerful exhaustion of the air or vacuum liberated gases by a vacuum pump before the water enters the centrifugal; second, tinning the vanes and guides. As yet we have no experience of result.

Venlo: Aggressive CO_2 observed all the time. This causes corrosion in the main, by which, during heavy demand, brown coloration of the water; water-meter parts attacked. By vigorously scouring the mains the brown-water troubles have been successfully combated. Neutralization of the acid is under consideration.

Wageningen: Aggressive CO_2 observed all the time. After some years' use some of the wells sanded up and it appeared that the brass filters were entirely corroded through solution of the zinc. After this filters of red copper were used which have remained intact. Cast-iron pipes were attacked and lumpy deposits appeared owing to which mains of small diameter no longer carried sufficient water. Cast asphalted steam pipes both in service mains and in houses choked up and rusted through. Repairing the mains destroyed the asphalting whereby the rust formation became more intense. In 1915 a trial plant for vacuum de-acidification (Sürth, Köln) was set up with favorable results. Too high a price unfortunately prevented its definite adoption. Consultations with Dr. Meerburg took place with reference to lime addition for acid removal. Most of the rust formation seemed to occur in that part of the system where most water was flowing and not in the dead ends. No organisms were found in the pressure mains ("fersleidingen").

Zwolle: It has been several times found that the waterpipes through the whole thickness of metal from inside to out had been changed into a carbon-like mass. This also occurred in the return circuit ("retourklep") of the high pressure apparatus. This may have been caused by aggressive CO_2. (This phenomenon is known as "verpotlooving.")

Comparing the water-supplies which, as seen from their answers to the questionnaire, show signs of "aggressiveness," with those for which this should be the case according to the examination by the Central Laboratory, the following appears:

In the following instances, signs of aggressivity, although they have no aggressive CO_2: Deventer, Gouda, den Helder, Maastricht. But the first two no longer show it. Other factors must therefore come into play here besides the free CO_2; among which oxygen should certainly be noted as taking the most prominent place. Both de-acidification and deaeration should bring about an improvement. Deventer chose the former plan and Maastricht advises the latter.

From the answers received, few in number though they be, of the water-supplies that have aggressive CO_2, it is yet clear enough how important the matter is for the water-supply-business. On the varying local factors it will depend whether deacidification is called for. When, for example, it is found too late that a water supply has aggressive CO_2 and the material for the mains has not been so selected that undesirable results are avoided, then deacidification will be necessary. Also the choice of the de-ironing system is de-

pendent on it. Thus, in cases where aggressive CO_2 is present (or, in general, much free CO_2) a closed system should not be used.

Conclusions. 1. From the literature and from practice it appears that hydrogen-ion concentration is of significance for drinking water and the water supply business.

2. From laboratory examinations and local observations, some 30 per cent of our (Dutch) water supplies give aggressive water, inclusive of the moor-water supplies and a few that use alum and such like.

3. In the questionnaire on aggressive CO_2, about half the water supplies have sent in replies; of these 20 per cent report signs of "aggressiveness," with important data. These signs are to be ascribed in part to the hydrogen-ion concentration and in part to other causes.

PART II. THE SIGNIFICANCE OF pH FOR DRINKING WATER, IN A PARTICULAR WATER SUPPLY IN ITS SUCCESSIVE PHASES (HEYMANN)

In the compilation of a report on the above, it seemed more practical to divide the task between Dr. Massink and the author in this way, that he devoted himself rather to the significance of pH for drinking water generally, while the author paid attention to its particular significance for the water supply business. In this the author has kept in view particularly the Amsterdam water supply. Seeing that this is composed of three separate supplies with relatively widely varied composition, it is fair to attribute a general significance to the report.

While Dr. Massink devotes his attention to drinking water supplies, the author has here equally considered the Amsterdam Vecht-water supply which is chiefly for industrial purposes. None the less, the purification of this supply is effected with so much care that the effluent could very well compete with many a Dutch drinking water.

In an article published in the *Chemical Weekblad*, 1919, pages 105–120, the author has already described this Amsterdam supply business in its chief outlines, and in order to avoid too much useless repetition, he will refer now and again to that article for fuller details.

The three Amsterdam supplies are the Dune water, the Bron water and the Vecht water.

The collection area of the dune water extends over nearly the whole of the dune district from Zandvoort to Noordwijk. The water drawn from this district is entirely derived from the rainfall, for various researches have shown that there can be no question of an underground flow hitherward from the East. Although in the final analysis, all our drinking water is, as a general rule, derived from the rainfall, it is not usually practicable to follow the water in its course from the moment that, in the form of rain, it strikes the earth to the moment that it leaves the tap. For the dune water this is, however, the case: by which statement we do not mean that absolutely every change the water undergoes is fully explained.

Dr. vander Sleen gives in his dissertation an exhaustive treatment of the chemical activity of the dune water at different depths and tries at the same time to account for the changes in chemical composition which take place in the earth beneath our dunes; in which he has given the importance they deserve to the carbonic acid and carbonates, which, as we shall see, determine completely the pH of the dune water. Of aggressive CO_2 there is no mention in this dissertation, while the pH question is also not raised, which last can hardly cause any surprise seeing that the study of it was still in the first stage of its development, especially in connection with its practical applications.

Before giving any figures the author acknowledges that he has only engaged in the study of pH for a relatively short time, so that probably the values here given will later, as a result of further research, be considerably changed. This applies more especially to the surface waters, the pH of which stands in the closest kind of relationship with the algae living in it, and in which a combination of circumstances may bring about wide changes from the average.

As the CO_2 content of rain water in the winter months just passed, values from 1.4 to 4.2 mgm. per litre were found, while the temporary hardness (0.70 to 0.90) was so small that, following Tillmans' tables, we can regard the CO_2 as practically entirely aggressive. The pH varied from 6.90 to 7.25.

As soon as this water reaches the earth important changes in its composition occur. If the earth is covered with vegetation and greater or less layer of humus, then the CO_2 content must increase considerably, especially in places where decaying vegetable matter furnishes a favorable culture medium for the bacteria and gives rise to free disengagements of CO_2. If the soil is bare and has little

organic matter, as is the case over large areas in the dune district, then the CO_2 increase from the influence of the earth is small. Directly coupled with this phenomenon is a reduction of the free CO_2 in this way that a portion of it unites with the almost universally present $CaCO_3$ which thus goes into solution as $Ca(HCO_3)_2$. The $CaCO_3$ content of our dunes varies between very wide limits; the old inland dunes are poor in lime, while the younger dunes, which comprise the greater part of the dune district of the Amsterdam water supply, are very rich therein.

The amount of vegetation and the thickness of the humus layer on the one hand and the lime content on the other, thus constitute the factors which in the main determine the CO_2 content of the water percolating into the earth. As both these factors may vary widely, it is not surprising that in the upper layers of the ground water we find widely varying composition of the water as the figures in table 1 show.

TABLE 1

WATER LINE	KIND OF GROUND	pH	$\frac{(H)}{10^{-7}}$	CARBONATE HARDNESS IN DEGREE	FREE CO_2	AGGRESSIVE CO_2
Zwarteveld no. 5..	Tilled, thick humus layer	7.35	0.45	19.3	49.0	−47.7
Westerveld no. 6..	Light growth	7.51	0.32	10.4	17.4	3.4
Westerkan W. no. 4	No growth	7.70	0.20	11.2	11.5	−4.5
Westerkan W. no. 7	Very light growth	7.75	0.18	8.7	9.0	0.8
Vinkenveld F.....	Tilled, practically no humus	7.75	0.18	7.0	7.1	3.2

Notwithstanding the high content of free CO_2 met with in the first sample beneath tilled land, no aggressive CO_2 appears to be present on account of the high carbonate hardness, a consequence of the lime-richness of the soil. The last sample exhibits the very opposite; little free CO_2 but at same time small carbonate hardness and consequently relatively high aggressive CO_2. Just as do the figures for total carbonic acid content, so too, only more so, the pH value gives quite a false picture of the aggressivity of the water.

A part of the dune water is derived from the upper levels along the coast line, the so-called "upper water," while another part, the deep dune water, is drawn from a formation at a depth of between 25 and 45 meters by tube wells, the so-called "Eemstelstel." Both

kinds are collected in shallow canals which intersect the dune district. From a number of the tube wells, just as for the previously recorded samples from the upper layers, determinations were made of the pH, the carbonate hardness and the free CO_2: and from the last two the aggressive CO_2 calculated. Some of the results are given in table 2.

TABLE 2

STATION	pH	$\frac{(H)}{10^{-7}}$	CARBONATE HARDNESS IN DEGREE	FREE CO_2	AGGRESSIVE CO_2
Van Stirumkanaal					
50	7.47	0.34	15.0	29.1	−15.1
55	7.44	0.37	15.0	31.8	−13.4
60	7.37	0.43	14.3	31.8	−5.7
65	7.48	0.33	11.8	23.3	2.4
70	7.49	0.33	10.4	17.9	3.7
75	7.53	0.30	12.5	21.2	−2.2
80	7.53	0.30	10.9	19.1	2.6
Westerkanaal					
10	7.47	0.34	15.7	30.0	−21.6
15	7.49	0.33	14.0	22.3	−12.7
20	7.62	0.24	15.7	19.3	−32.1
25	7.49	0.33	14.8	24.9	−17.5
30	7.50	0.32	13.4	2.23	−7.4
Boogkanaal					
5	7.67	0.21	13.0	15.7	−11.5
10	7.65	0.22	14.1	17.6	−18.3
15	7.65	0.22	14.1	17.6	−18.3
45	7.68	0.21	14.1	18.0	−17.9
50	7.78	0.17	13.2	13.1	−15.4

For the water of the wells of the Van Stirum and the Wester Canals, which for almost their entire length run parallel with the sea coast, the pH varies but little. Carbonate hardness and free CO_2, on the contrary, show relatively wide variations. But the aggressive CO_2 gives here very remarkable figures or rather the deficiency of CO_2 from the quantity which should be present for equilibrium with the $Ca(HCO_3)_2$ content, which for shortness is called the "appropriate" (bijbehoorend) CO_2. Some of the Van Stirum Canal wells give aggressive water: the greater part of the wells of this canal and all

those of the Wester and Boog canals show a greater or less deficiency of "appropriate" CO_2. Very probably there was originally an equilibrium; that is to say, the water which penetrated the earth continued to take up $CaCO_3$ until all the aggressive CO_2 had disappeared and the CO_2 remaining free was just in equilibrium with the $CaCO_3$ content which the water then had.

The composition of the dune water is not readily determined, inasmuch as the water is not collected as such and this is for some time enclosed in the canals; consequently such changes take place, reflected again in the pH, that analysis can no longer give a just picture of the true composition of this water.

The pH of all the water which is of any importance in the Amsterdam supplies is regulated by the presence of CO_2 and carbonates. It is true there is in the dune region a well district which gives water with humus acids: but these wells which give an inferior water are in ordinary times not drawn on and need an apparatus for direct pH determination, so it has been impossible to extend the experiments to them.

TABLE 3

KANAAL	pH	$\frac{(H)}{10^{-7}}$	CARBONATE HARDNESS IN DEGREE	FREE CO_2	AGGRESSIVE CO_2
v. Stirumkanaal.....	8.10	0.08	13.0	4.9	−22.1
Nieuwe kanaal.....	8.05	0.09	13.8	6.0	−27.3
Zwarteveldkan.....	8.10	0.08	12.2	4.6	−16.8
Boogkanaal.....	7.85	0.14	14.3	10.2	−27.5

In the shallow open canals through which the water slowly flows, it loses first a share of its CO_2 to the air, while a considerable proportion is assimilated by the numerous algae growing in these canals. If the well water contains any considerable concentration of iron, then, for two reasons, we may expect a lower pH in the canal than for a water less rich in iron, of otherwise identical composition. First, free CO_2 is liberated by decomposition of $Fe(HCO_3)_2$; and, in the second place, the ferric hydroxide formed hinders by light absorption the algae growth. This phenomenon is especially noticeable for the water of the Boog canal, as the figures in table 3 show, which refer to samples drawn from the delivery end of the canals.

These determinations were made in February; in spring and summer still lower pH values are to be expected.

The canal waters are collected in the Oranjekom, a reservoir about 1.5 meters deep with an area of about 2 hectares excavated on the dunes. Form this it is conveyed by a main 1360 meters long to a pair of raw water reservoirs. For want of light the CO_2 assimilation process is at a standstill in the main and in these reservoirs, while the organisms of those kinds which are in the water by their respired CO_2 bring down the pH value somewhat.

From these raw water reservoirs the water is pumped on the pre-filters, pits of 100 square meters area, in which there is a meter-thick layer of gravel ("grint") of 2–6 mm. size. These pre-filters are set up in a shed ("loods)" where the light is mostly cut off, so that no algae growth takes place in the upper water. By the very great number of bacteria that flourishes in these filters, a very considerable portion of the soluble organic matter of the water is oxidized, while otherwise no chemical changes occur which influence the pH. But the fact just mentioned is the cause of a relatively great reduction in the pH.

The water thus prefiltered and now perfectly clear comes on to the after filters, basins of an average area of 3000 square meters which have a layer of dune sand about 100 cm. deep. In the upper water of these filters a very luxuriant growth of algae takes place. In the winter and early spring the diatoms predominate while in the rest of the year the filament forms have the upper hand. In this connection, the diatoms effect a very marked assimilation of CO_2. Tillmans says in an article which is discussed a little later that those cases in which, along with much HCO_3 there is but little free CO_2, in actual practice play an important part, because there must always be free CO_2 present with $Ca(HCO_3)_2$ if the latter is to be stable. He goes on to specify strong aeration as the process by which the CO_2 content of the water can be brought down to a very small amount. He very improperly here leaves altogether out of consideration the algae: and they, indeed, constitute a very powerful means of removing CO_2 from the water. While by spraying the water as is done at Leiduin in the prefilters, one can reduce the CO_2 concentration by a few milligrams in the upper water of the after filters, in sunny weather the CO_2 concentration goes down to nil. Up to now the author has never observed complete absence of CO_2. One proof of this disappearance of CO_2 being due in practice to biological action is that the assimilation process is at a standstill during the night.

One often sees the opinion advanced that a deficiency of "appropriate" free CO_2 gives rise to an immediate deposition of $CaCO_3$. Nothing is less true. The dune water carries on an average 385 mgm. Ca $(HCO_3)_2$ per liter. When from this water all the free CO_2 is removed, as may occur in the upper water of the filters in the manner just described by means of the algae, nevertheless this water remains perfectly clear for days. One may even drive off the CO_2 by boiling without bringing about separation of $CaCO_3$. The pH of such water is 8.25 to 8.30, corresponding to a hydrogen-ion concentration of 0.056 to 0.050.

In the passage through the sand bed of the after filters some of the organic matter in solution is oxidized by the bacteria, whereby the CO_2 concentration and with it, of course, the (H^+) increases. Nevertheless this last is always lower than in the "fore-filtrate," owing to the strong reduction it suffers before the water percolates into the sand bed.

The filtered water is collected in a purified water reservoir and pumped from there by two mains to Amsterdam where it again flows into a storage reservoir before finally being brought into the city system. During the whole journey from the filters to the city mains, the water undergoes almost no alteration; neither the CO_2 content nor the pH is altered. Here especially is it most clearly manifested that a deficiency of "appropriate CO_2" does not give rise to a rapid separation of $CaCO_3$, even when the water is in contact with $CaCO_3$ crystals. The deficiency of "appropriate CO_2" in the filtered water is always from 10 to 20 mgm. on an average. It is true that $CaCO_3$ is deposited in the reservoir, but the quantity is very small—the amount at Leiduin in the course of a whole year is only a few dozens of kilograms. The $CaCO_3$ which separates in the mains partly attaches itself to the walls and thus forms the protective layer: while that part which separates free in the water is carried forward by the stream and in the filtered water reservoir in Amsterdam it settles out. The amount of this last likewise only comes to a few dozens of kilogrammes in the year. While if all the calcium bicarbonate which is in the water in excess, in respect to the content of free CO_2, were to be precipitated as $CaCO_3$, and assuming the deficiency of "appropriate CO_2" at only 10 mgm. per liter, a matter of about 190,000 kgm. a year of $CaCO_3$ would accumulate in the filtered water reservoir.

The Vecht water supply formerly, as the name implies, drew its water from the river, the Vecht. At the beginning of the working, an arrangement was made by which water could also be taken from the Merwede Canal; and as this last appeared to be in some respects preferable to the Vecht water, mostly Merwede Canal water was used afterward. This water shows a considerably different composition from the dune water. It has a lower carbonate hardness and thereby more readily acquires aggressive CO_2. At the Weesperkarspel pumping station it undergoes a somewhat different treatment from that applied at Leiduin to the dune water. After flowing through a 4000 meter long main, it is pumped out of a relatively small raw water reservoir into two settling basins of 40,000 cubic meters content each, in order to settle out the larger impurities. The water is generally turbid and has a permanganate consumption of 15 to 40 mgm. $KMnO_4$ per liter. It has dozens of bacteria to the cubic centimeter and only a few algae. In short, CO_2 development is readily brought about in various ways and CO_2 absorption is hindered. In the autumn and winter when the algae life is reduced to a minimum and CO_2 assimilation is nearly at a standstill, a low pH value is found and the water shows aggressive properties. When on the other hand in the spring the algae and especially the diatoms come to the front the pH goes up and instead of an excess, there is a deficiency of "appropriate CO_2."

Until very lately the author had never noticed that the CO_2 in the sedimentation basins was altogether used up. This unusual phenomenon showed itself this year in March for the first time and lasted for some weeks. The water reacted more or less strongly alkaline to phenolphthalein. The pH ran from 8.3 to 8.7 with a HCO_3 concentration of 190 mgm. per liter on an average and a CO_3^{--} concentration of 0 to 6.6 mgm. per liter. The reason for the phenomenon seems to lie in the presence of a very great quantity of diatoms in the water. By count, for example, amongst others, 2,200 of these silicic algae to the cubic centimeter were found: and principally *Asterionella gracillima* and *Diatoma elongatum*. The water appeared slightly turbid from the diatoms and accompanying this phenomenon, as is no cause for surprise, was a supersaturation with oxygen.

From the sedimentation basins the water is led upon four filters, which are about one and one-half times as large as those of the dune supply, but in other respects, at least in all the chief points, constructed in the same way. The sedimentation makes the water less

turbid; besides which it stands in the after filters only 75–100 cm. over the sand bed, so that the light has everywhere abundant access. As a result a luxuriant vegetation of algae is brought about, by which the same phenomenon may occur as was repeatedly observed at Leiduin, namely that on sunny days the CO_2 reaches almost total exhaustion. The pH reaches in this way values from 8.25 to 8.29. To total absence of free CO_2, that is, red coloration of water with phenolphthalein, it comes only in so far as experience to date can be taken as a guide, when the water carries a very great quantity of diatoms, as was the case in March and April of this year (1920).

The millions of diatoms which, specially in the spring, appear in the filters, are mostly benthonite forms which cover the sand bed as a more or less adherent layer. Massa's plankton forms, such as were found this year in the Merwede Canal, are exceptional, at least in the Amsterdam water supplies. Probably their appearance had some connection with the abnormally mild weather conditions of this spring.

The filter coat of the after filters completely retains the suspended matter, so that the water after passing through this stratum of algae is perfectly clear. However, it still has much organic matter in solution, which to some extent is attacked by the billions of bacteria inhabiting the sand bed, by which process CO_2 is developed. Thus the pH value is reduced during the passage through the sand bed. In the upper layers of the sand bed there is still for the most part a deficiency in "appropriate CO_2;" while, when leaving the filter, at least in the autumn and winter months, the water usually has aggressive CO_2. Besides being shown by the analysis, this can also be observed in practice from the fact that a litt'e $CaCO_3$ can still be found in the filter sand, while in the filtered water reservoirs none is found.

The very rapid coming to life of the world of diatoms in March is the reason for the great alteration undergone by the pH value in this month, compared with the preceding winter months, during which the CO_2 development has the upper hand of the CO_2 assimilation.

The monthly averages given in table 4 bring out this clearly.

In consequence of the abnormally mild winter (1919–1920) we have just had, and in close relation therewith the relatively high temperature of the water, the algae growth was very strong even in

January, and consequently these figures are less striking than would have been the case under more normal conditions.

The Bron water supply is derived from the district all the way from Hilversum to Noorden. The water is drawn from the diluvial strata by 15 wells which have an average depth of 38 meters. This water is so pure and has so little iron that it can be carried into the transport main direct without any preliminary treatment. The composition of the water is practically constant.

The average carbonate hardness amounts to only 4.45°, so that here aggressive CO_2 may be expected much sooner than in the Merwede Canal water, although, then, the CO_2^- concentration is very low, viz., only about 6 mgm. per liter, yet fully 4 mgm. of it is aggressive, calculated according to Tillmans' tables.

TABLE 4

	SETTLED WATER				FILTERED WATER			
	pH	$\frac{(H)}{10^{-7}}$	Free CO_2	Aggressive CO_2	pH	$\frac{(H)}{10^{-7}}$	Free CO_2	Aggressive CO_2
January	8.0	0.10	4.0	−2.7	7.8	0.16	7.1	0.5
February	8.1	0.08	3.9	−6.4	7.9	0.13	5.7	−3.5
March	8.3	0.05	1.3	—	8.05	0.09	4.5	−4.2
April	8.6	0.025	0	—	7.9	0.13	4.9	−2.2

pH of 7.58 was found as the average for this water, corresponding to $(H^+) = 0.26 \times 10^{-7}$. Determination of the concentration of aggressive CO_2 according to Heyers' marble test gave results in good agreement with the calculated concentration according to Tillmans' tables.

In water which had 6.1 mgm. CO_2 per liter and 4.48 carbonate hardness consequently, according to Tillmans, with 4.4 mgm. aggressive CO_2, there was, after 4 days shaking with marble powder in a quite full stoppered bottle, a CO_2 concentration of 2 mgm. per liter; from which would follow an aggressive CO_2 concentration of 4.1 mgm. While the pH was originally 7.58, this rose by the marble treatment to 8.05 corresponding to $(H^+) = 0.09 \times 10^{-7}$. The new carbonate hardness was 5.05 from which taken in connection with the original carbonate hardness may be inferred that the water had 4.4 mgm. aggressive CO_2.

The aggressiveness of this water shows itself in practice by the fact that no protective coating of $CaCO_3$ is formed, consequently

the metal of the mains is exposed to the corrosive action of the water.

The above mentioned determinations of the pH value were all carried out by the indicator method, using for the most part as standards KH_2PO_4 and Na_2HPO_4; while in the cases where pH was over 8.1, borax-HCl mixtures were mostly used. Neutral red was chiefly employed as indicator, which even for very small changes in pH gives considerable change in tint, and in this respect is far preferable to azolitmin, which was also sometimes made use of and which certainly has a wide range, but in which the color changes are much less striking. For water with pH over 8.3 phenolphthalein was used.

Not having an apparatus for direct pH determination, the work was exclusively colorimetrically, which was here always possible inasmuch as the author always had practically colorless water with which to work.

The indicator method in one respect is certainly preferable to the direct method. Quite apart from those cases in which the presence of ammonium sulphide renders the latter method unworkable, the determination can quite readily be made on the spot where the sample is taken. This is highly desirable whenever one has to do with water which has much CO_2, for notwithstanding every precaution, loss of CO_2 in transport can with difficulty be altogether avoided.

As to the manner in which the pH is expressed the method given by Tillmans is much to be recommended, namely in ten-thousandths milligrams H-ion per liter, which gives figures much more convenient for comparison than Sörensen's numbers. Hence it is that in the tables the author always gives the value of $\frac{(H^+)}{10^{-7}}$, corresponding to Tillmans' "h."

In the above referred to article of Tillmans, he gives formulae for the calculation of pH or h, from the content of free CO_2 and HCO_3 of the water, deduced from the mass action law of Guldberg and Waage. He differentiates four possibilities:

(a) Free CO_2 alone is present.
(b) Much free CO_2 and much HCO_3 are present.
(c) The water has much free CO_2 and very little HCO_3.
(d) The water has much HCO_3 and very little free CO_2.

The second case is the most usual in the business of water supply. From the equation $H_2CO_3 \rightleftarrows H^+ + HCO_3^-$ follows:

$$\frac{(H^+) \cdot (HCO_3^-)}{(H_2CO_3)} = K. \text{ : or } (H^+) = K. \times \frac{(H_2CO_3)}{(HCO_3^-)}$$

As only a very small portion of the H_2CO_3 is ionised, we can replace in practice the (H_2CO_3) by the total concentration of free CO_2. Further, Tillmans assumes the bicarbonate to be almost completely ionized, so that we can assume for (HCO_3^-) the total concentration of HCO_3^-. Dividing the numerator and denominator of the fraction by *44,000* we get the concentration of the free CO_2 and the bicarbonate in milligram per liter, so that we can finally write the formula

$$(H^+) = K_1 \times \frac{\text{free } CO_2}{\text{bicarbonate } CO_2}$$

or, since $K_1 = 3.04 \times 10^{-7}$; approximately,

$$h^\circ = \frac{3 \text{ x free } CO_2}{\text{bicarbonate } CO_2}$$

Tillmans shows by calculations that we can in practice almost always make use of this simple formula. Only when the CO_2 concentration is very small in proportion to the HCO_3^- concentration do the deviations become too great, because in this case the CO_3^- ions, resulting from HCO_3 by further dissociation, can no longer be neglected. Tillmans assigns 1:40 as the limiting ratio.

Just as the CO_2^- content alone fails to give a picture of the aggressivity of the water, so, too, are we unable to form an opinion thereon on the basis of pH. Just as to each concentration of $Ca(HCO_3)_2$ which the water may have there belongs a certain concentration of free CO_2 which is necessary to retain this $CaCO_3$ in solution, which CO_2 will exhibit no aggressive properties with respect to chalk, cement, etc., so, too, to every $Ca(HCO_3)_2$ concentration belongs a certain pH. Only when this concentration of H-ion is exceeded does the water exhibit aggressive characteristics with respect to the substances mentioned above. In such water the material of the mains is not coated with a protective layer of $CaCO_3$ and thus phenomena of corrosion may arise, of which, from the point of view of sanitary significance, the attacking of lead is the most dangerous.

Tillmans has calculated the "appropriate" pH for water of different HCO_3^- concentration and has assembled the data in a table.

In table 5 are given for a number of samples of water, first the three figures found by direct determination for HCO_3^- content, pH, and free CO_2. Further, the last column but one gives the difference between the pH found and that appropriate to the carbonate hardness; and finally in the last column is given the concentration of aggressive CO_2 calculated with the help of Tillmans' table. These samples were collected on different dates and are therefore not suited for mutual comparison, such for example as

TABLE 5

SOURCE OF SAMPLE	BICARBONATE	$\frac{(H)}{10^{-7}}$	CO_2	APPROPRIATE CO_2	APPROPRIATE $\frac{(H)}{10^{-7}}$	DIFFERENCE IN $\frac{(H)}{10^{-7}}$	AGGRESSIVE CO_2
Zwarteveld no. 5	303.6	0.45	49.0	96.7	0.96	−0.51	−47.7
Westerveld no. 6	162.8	0.32	17.4	15.2	0.23	0.09	3.4
Westerkan no. 7	136.4	0.18	9.0	7.0	0.15	0.03	0.8
v. Stirumkanaal source 60	224.4	0.43	31.8	37.5	0.51	−0.08	−5.7
v. Stirumkanaal source 70	162.8	0.33	17.9	12.2	0.23	0.10	3.7
Westerkan source 20	246.4	0.24	19.3	28.1	0.64	−0.40	−32.1
Leiduin Ruw	202.4	0.13	8.8	26.1	0.38	−0.25	−17.3
Leiduin Voorfiltr	200.2	0.23	14.9	25.0	0.37	−0.14	−10.1
Leiduin Nafiltr	200.2	0.10	6.6	25.0	0.37	−0.27	−18.5
Vechtw. Bezonken	136.4	0.14	6.5	7.0	0.15	−0.01	−0.5
Vechtw. Reinw	136.4	0.18	7.5	7.0	0.15	0.03	0.4
Bronwater	70.4	0.26	5.8	1.4	0.06	0.20	4.1
Diepb. Z. 4900, p. 3	334.4	0.31	35.2	127.0	1.14	−0.83	−91.8

"prefiltered" with "filtered," etc. They are given merely as arbitrarily chosen examples to bring out the correspondence between theory and practice.

From the concentration of HCO_3^- and of free CO_2 can, as we have seen, the pH be calculated. While of course, vice versa, we can also, from the first and second determination, calculate the free CO_2. In this way we have a control over these figures. The calculation of the CO_2 is very advantageous, for example, when we have an iron-containing water, the CO_2 content of which is difficultly determinable by direct titration, or impossible to determine entirely, while we, by taking a few precautions in order to exclude as far as possible the oxygen of the air, and working rapidly, preferably

on the spot where the sample is taken, can determine very closely the HCO_3^- content and the pH, and from these can calculate approximately the CO_2, so that we have results of value for practical purposes, as a control by determination of the total CO_2 content will show. Apart from interference by iron, absolutely exact results are not to be expected, inasmuch as Tillmans assumes a complete dissociation of Ca $(HCO_3)_2$. This may very well be the case for water which has but little $Ca(HCO_3)_2$, such for example as the Amsterdam Bron water; for the very hard dune water we should in this way fall into error, and should find a higher value for the

TABLE 6

SAMPLE	pH FOUND	pH CALCULATED	$\frac{(H)}{10^{-7}}$ FOUND	$\frac{(H)}{10^{-7}}$ CALCULATED	BICARBONATE	FREE CO_2 FOUND	FREE CO_2 CALCULATED	$\frac{CO_2 \text{ FOUND}}{CO_2 \text{ CALCULATED}}$
v. Stirumk. br. 60	7.37	7.37	0.43	0.43	224.4	31.8	32.2	1.01
Leiduin Ruw	7.88	7.90	0.13	0.13	202.4	8.8	8.8	1.00
Leiduin Voorf	7.80	7.80	0.16	0.16	200.2	10.5	10.7	1.01
Leiduin Reinw	8.00	8.05	0.10	0.09	195.8	6.1	6.5	1.07
Vechtw. bezonken	8.20	8.15	0.06	0.07	162.8	3.7	3.3	0.89
Vechtw. Reinw	7.95	8.00	0.11	0.10	140.8	4.6	5.2	1.13
Bronwater	7.58	7.60	0.26	0.25	70.4	5.8	6.1	1.05
Leiduin filt. 3	7.70	7.73	0.20	0.19	202.4	12.7	13.5	1.06
Diepb. W. 510, p. 5	7.70	7.62	0.20	0.24	228.8	17.6	15.3	0.87
Diepb. Z. 4900, p. 6	7.58	7.53	0.26	0.27	215.6	19.1	18.7	0.98

CO_2 calculated after Tillmans than that obtained by direct titration. As, however, the CO_2 concentration in the samples examined is small, and it is difficult to titrate closely such small concentration, no striking figures were obtained in this respect.

That we can nevertheless very well adopt Tillmans simplified formula in practice is seen from table 6 for water of various composition from the Amsterdam water supply. In the last column is given the ratio of the CO_2 found to the calculated concentration.

We can thus, as appears from the above consideration, deduce the concentration of aggressive CO_2 from the pH and the carbonate hardness, two determinations, both of which we can effect on the spot, which for practical purposes, is of the very greatest importance. Moreover it is not necessary that we should first calculate the

free CO_2 from these data, in order to determine the concentration of aggressive CO_2 either by help of Tillmans' table or Auerbach's curve: but we can very closely predict this last by subtracting from the pH found, the pH appropriate to the HCO_3^- concentration found, and dividing the result by 0.03. This method of calculation is, however, not exact for water which has less than 100 mgm. bicarbonate CO_2 per liter; while its accuracy further decreases according as the content of aggressive CO_2 increases. With a content of aggressive CO_2 of 25 mgm. per liter, the error amounts to about 2 mgm. Thus even in this case results of value for practical purposes are obtained.

In the same way as Tillmans has adapted the law of mass action for the calculation of pH in CO_2-rich water, we can do this for CO_2-free water, such as was found this year in the sedimentation basins and the filters of the Weesperkarspel Pumping Station.

We have in this case to do with a mixture of carbonate and bicarbonate, the concentration of which can be obtained by titration with HCl, using respectively methyl-orange and phenolphthalein as indicators. From the formula of the mass-action-law, since in this case

$$HCO_3^- \rightleftarrows H^+ + CO_3^{--}$$

it follows that:

$$\frac{(H^+) \,.\, (CO_3^{--})}{(HCO_3^-)} = K_2$$

or

$$(H^+) = K_2 \times \frac{(HCO_3^-)}{(CO_3^{--})}$$

where

$$K_2 = 6 \times 10^{-11}$$

When we have to deal with a CO_3^{--} concentration which is very small in comparison with the HCO_3^- concentration, we cannot neglect the CO_3^{--} ions derived from the bicarbonate ions in accordance with the equation:

$$2\ HCO_3^- \rightleftarrows H_2CO_3 + CO_2$$

and we can, in a similar way to that in which Tillmans has done it for carbonic acid containing water, develop an accurate formula for the calculation of pH.

We find then:

$$(H^+) = \sqrt{\frac{K_1 K_2 a}{a + 2b} + \left(\frac{bk_1}{2a + 4b}\right)^2} - \frac{bk_1}{2a + 4b}$$

Where a denotes bicarbonate CO_2 concentration and b the free CO_2 concentration, both expressed in milligram per liter.

Auerbach and Pick have followed this method in order, from the pH, the (HCO_3^-) and the (CO_3^{--}) concentration to determine the value of K_2.

If the (CO_3^{--}) is not too small in proportion to the (HCO_3^-), we can then make use of the simple formula:

$$(H^+) = 6 \times 10^{-11} \frac{\text{bicarbonate } CO_2}{\text{carbonate } CO_2}$$

The author has examined more closely how far it is necessary to use for the Merwede Canal water the very complicated accurate formula, and has to this end calculated the pH for various concentrations of CO_3^{--} according to the two formulae. At the same time he gives in table 7 the (OH^-) which is more rational for these alkaline waters. For this the value $K_w = 0.74 \times 10^{-14}$ (18°C.) has been assumed.

TABLE 7

BICARBONATE	CARBONATE	H-ION CONCENTRATION $\times \frac{1}{10^{-7}}$		OH-ION CONCENTRATION $\times \frac{1}{10^{-7}}$		H EXPONENT	
		Simple formula	Accurate formula	Simple formula	Accurate formula	Simple formula	Accurate formula
140	8	0.0105	0.0100	71	74	8.98	9.00
140	6	0.0140	0.0127	53	58	8.85	8.90
140	4	0.0210	0.0174	35	42	8.68	8.76
140	2	0.0420	0.0259	18	28	8.38	8.57

From this it is apparent that for water which contains such low concentrations of CO_3^{--} as were here found for the Merwede Canal (the greatest concentration of CO_3^{--} amounted to 4.8 mgm. per liter of carbonate—CO_2) we can no longer employ the simple formula.

The titration of such small concentrations of CO_3^{--} moreover occasions so much difficulty, that it is actually desirable to reverse the procedure and calculate the CO_3^{--} concentration from the pH and the HCO_3 concentration.

Three more examples from actual working, relating to settled Merwede Canal water, are given in table 8.

That the pH value found does not always give a good agreement with the calculated has its reason chiefly in this, that it is difficult accurately to determine such small CO_3^{--} concentrations as are

here in question. Moreover, the author has, as Tillmans also did, assumed in his calculations that the Ca^{++} salts in the water are completely dissociated, which is not actually the case. In this way, too, an error is introduced, even if it be of little practical significance.

TABLE 8

DATE	BICARBONATE CO_2 IN MILLIGRAMS PER LITER	CARBONATE CO_2 IN MILLIGRAMS PER LITER	pH FOUND	pH CALCULATED
March 30	141.2	4.4	8.60	8.80
April 6	135.5	4.8	8.70	8.79
April 13	140.0	2.6	8.48	8.61

Summarizing the conclusions to which the above-described experiments have led, we can thus say:

1. From Guldberg and Waage's Law of Mass Action the relations between the pH the concentration of the bicarbonate CO_2 and the concentration of free CO_2 may be calculated.

2. This relation is, as Tillmans has pointed out, very simply to be represented by formula:

$$h' = \frac{3 \times \text{free } CO_2}{\text{bicarbonate } CO_2}$$

where h' represents the concentration of H^+ expressed in ten thousandths milligram per liter, while the free CO_2 and bicarbonate CO_2 are expressed in milligrams per liter.

This formula is only approximate: but it is for the majority of cases sufficiently accurate for practical purposes.

3. Whenever we have determined two of the above mentioned values, we can thus always calculate the third.

This has its application in the water supply business when for instance the direct CO_2 determination by titration presents difficulties, as is the case in presence of iron salts.

When all determinations can be made then the formula gives us a convenient method to control the values found.

4. If the water has no free CO_2, which case as we have seen may actually occur in practice, we can again adopt the law of mass-action which in this case leads to the formula:

$$(H^+) = \sqrt{\frac{K_1K_2a}{a+2b} + \frac{(bk_1)^2}{(2a+4b)^2}} - \frac{bk_1}{2a+4b}$$

where a denotes the bicarbonate CO_2 and b the carbonate CO_2, both expressed as milligram per liter.

If the CO^{3--} concentration is not too small in proportion to the HCO_3^- concentration we can use the simple formula:

$$(H^+) = 6 \times 10^{-11} \times \frac{\text{bicarbonate } CO_2}{\text{carbonate } CO_2}$$

5. In this connection, the indicator method for pH determination can give good service, because we can carry it out in the field, which is in most cases desirable and in some cases imperative.

6. When we have determined the pH and the carbonate—hardness of water, we can then in a very simple way approximate to the concentration of aggressive CO_2 by dividing by 0.03 the difference between the "pH" found and that which corresponds to the hardness found, both expressed in ten thousandths milligram per liter. We obtain thus results sufficiently accurate for practice provided the bicarbonate CO_2 concentration is not less than 100 mgm. per liter.

DISCUSSIONS

EFFECTIVE DILUTION AS A POLLUTION UNIT

The paper entitled "Effective Dilution as a Pollution Unit" by Wm. Firth Wells appears in this issue because it is the policy of the Publication Committee not to stifle publicity of the ideas of contributors to the JOURNAL, even though the Committee sometimes finds it difficult to reconcile with actualities the data presented. The paper by Mr. Wells is a case in point.

Mr. Wells' basic premise involves the reduction of the pathogenicity of sewage pollution by means of dilution with pure water. Theoretically the idea is sound, but practically it is not capable of exploitation. In lieu of purification of polluted water by such widely used artificial means as sedimentation, coagulation, filtration, and sterilization, he would dilute the pollution with pure water to a point where on analysis the same bacterial results would be returned as when the water is purified by such artificial means. There is nothing especially revolutionary in the idea except that it is based upon theoretical premises and cannot be accomplished in practice.

The real objection to the "purification by dilution" idea is that to be really and consistently effective it must be demonstrated that it is always possible to so dilute the pollution, that is, to mix each unit of pollution with the requisite number of units of pure diluting water. Everybody who has had to deal with such matters knows positively that this cannot be done with any degree of certainty.

Mr. Wells states that "in actual practice sanitarians have arrived at a time factor for storage reservoirs which may be considered the equivalent of safe water purification." The writer would like to know where this is being done, and who is responsible for it. Such a tentative conclusion may have been reached by some sanitarian, all bound 'round with a woolen string of qualification, but that such an idea has been adopted, and is in actual practice, the writer very much doubts. If it is, the consumers of that water are taking an awful chance with their health and their lives. We know too much

about the vagaries of storage reservoirs; how various disturbing factors like currents, wind action, seasonal overturns, and the like can and do upset all human calculations in this regard. In theory such an idea is all right, but in practice it is all wrong. If storage reservoirs would "stay put" all of the time, and if a consistently reliable period of quiescent storage always could be counted upon, and never fail, then all would be well. But storage reservoirs or lakes *will not* stay put.

If it is the author's desire to revolutionize the art of water purification the writer submits that he had far better devote his time to research into the still existing defects in modern processes of artificial water purification. At least in this field he will be dealing with instruments which he can reasonably control. Bodies of water which he would now use for dilution of pollution he cannot control, nor can he reliably effect in practice the complete mixture of polluted with pure water so as to obtain a mixed water as consistently suitable for human consumption as can be secured by existing artificial processes of water purification. To say the least these artificial processes in a very material degree are amenable to human direction and control.

GEORGE A. JOHNSON.

PRACTICAL WATER WORKS INFORMATION

For several years, successive Publication Committees have done their best to bring about a more free interchange of information on the so-called practical features of water works management. They have not been successful in this, although every suggestion that seemed to have the slightest chance of producing results has been tried thoroughly. The Constitution says that the Publication Committee shall not print "papers containing matter readily found elsewhere, especially advocating personal interests, carelessly prepared, purely speculative or foreign to the purpose of the Association." No two men will agree exactly on the interpretation of this rule in every case, but during the period the writer has been on these committees there has been good working unanimity of opinion.

This is the last number of the JOURNAL to appear before the annual convention, and the writer is, therefore, taking advantage of the opportunity to express the hope that members of the Association at the convention will give to the Publication Committee all

suggestions that occur to them which will help in developing the practical side of the Association's published information. It is a fact that the practical side of water supply furnishes less printed information than any other branch in the entire field of public utilities. It has been so for many years. Gas, electricity, sewerage, roads and streets furnish far more information of this kind, and have always done so, yet there is no intrinsic reason for it other than the unwillingness of water works operators to cooperate in getting good information into print.

From time to time the suggestion has been made that the members would like to have the oral discussions, after revision by those taking part, printed without substantial condensation. The present cost of printing is very high and to carry out this plan will involve a large addition to the cost of the JOURNAL as it has been produced for some years back. A large proportion of the members to whom the reports of their oral discussions are sent return them as, 1, not worth printing, or, 2, not at all what they said, or, 3, too confused to be rewritten. The remainder are sometimes rewritten and sometimes returned with a mark of approval as they stand. The part that is returned does not represent the entire discussion, is often almost unintelligible in places on account of the omissions, and would very rarely be printed in any form in a journal published commercially. It is for these reasons, financial and practical, that the writer believes it is unwise to print discussions of papers unless they can be rearranged into a form which will give useful or interesting information without excessive verbiage. But the JOURNAL is printed for the members, and if they desire to have an attempt made to report discussions more elaborately in its pages, the Publication Committee will be very glad indeed to know about this.

The greatest help the Publication Committee can have, however, is advice from members concerning subjects upon which they desire information. This will give the Committee an opportunity to get together data which will certainly interest one member and will probably interest many members. The publication of short practical articles of this nature, once started, will make the JOURNAL more useful and, in time, will prove to a good many members who may now believe the Publication Committee to be a rather dead body, that the fault has not been with the Committee any more than with the membership as a whole.

JOHN M. GOODELL.

REPORT OF THE JOINT COMMITTEE ON STANDARD SPECIFICATIONS FOR WATER METERS

The Joint Committee of the American and New England Water Works Associations, on Standard Specifications for Water Meters, submits its final report, accompanied by a draft of Standard Specifications for Cold Water Meters, Disc Type, which it recommends for adoption; a statement of the information which should be furnished to meter manufacturers when requesting bids under the proposed specifications; a description of the equipment necessary to test meters for compliance with the registration and capacity requirements of the specifications; and a statement of tests recommended.

Appointment, organization and meetings of committee. The formation of a committee on meter specifications was suggested by R. J. Thomas, who presented a brief paper to the convention of the New England Water Works Association at Portland, Maine, in 1916, calling attention to the desirability of uniform standard specifications for meters. Following the presentation of that paper it was voted that a committee of the New England Water Works Association be appointed.

In 1919, upon the representation of members of the New England Association's committee to the American Association, the latter voted to appoint a similar committee, which was done forthwith.

The first actual meeting of the Joint Committee, or of either of the committees appointed by the Associations, was held on March 9 and 10, 1920. Prior to that time such progress as had been made was accomplished by correspondence.

It was immediately decided to organize as a Joint Committee, and to make a single report to both Associations. The committee organized with Charles W. Sherman as Chairman and Seth M. Van Loan as Secretary.

At the conclusion of the meeting of March 9 and 10, 1920, a sub-committee consisting of Messrs. Saville, Brush, Van Loan and McMurry, was appointed, to give further consideration to points raised in the main committee, to carry out certain experimental work, and to obtain some further information from the manufacturers, and to report back to the Joint Committee at a later date.

The second and concluding meeting of the Joint Committee was held February 8 and 9, 1921, at which time the draft of the specifications was tentatively adopted and the form of the report considered. The final work of the committee has been accomplished by correspondence.

Preliminary work of New England Water Works Association Committee. Correspondence between the members of the New England Association's committee began soon after the original appointment in 1916, but before anything of significance had been accomplished the United States entered the World War and it became impracticable for the members of the committee to devote any material amount of time to committee work. Late in 1917, however, the Department of Water Supply, Gas and Electricity of New York City prepared a tentative draft of specifications, under the direction of W. W. Brush, a member of the committee. After further correspondence between the members of the Committee it was planned to print these tentative specifications as a basis for discussion, and submit them to the 1918 convention of the New England Water Works Association, as a progress report, but before this was done information from the manufacturers indicated that certain points in the tentative draft should be discussed with the manufacturers before submitting them to any convention, and the draft was therefore not circulated.

Draft of specifications prepared by meter manufacturers. During 1918 and 1919 the manufacturers on water meters held a series of conferences under the auspices of the Meter Manufacturers' Exchange but to which manufacturers not members of that Exchange were invited, at which they discussed the subject of specifications and finally prepared a draft of standard specifications acceptable to all of them. These conferences were held in New York City and during the latter part of the time were attended by W. W. Brush, as representative of the New England Association's committee. They concluded in February, 1920, when a draft of standard specifications acceptable to the manufacturers was completed.

The Meter Manufacturers' Exchange includes the Buffalo Meter Co., Hersey Manufacturing Co., Neptune Meter Co., Pittsburgh Meter Co., Thomson Meter Co., Union Water Meter Co., and Worthington Pump and Machinery Co. Other manufacturers not members of the Exchange are Badger Meter Co., Gamon Meter Co., and National Meter Co. It is the understanding of the Committee that all of the manufacturers were either represented at the

conferences or subsequently assented to the action taken at those meetings.

The specifications thus drafted and submitted to the Joint Committee of the Water Works Associations covered both the disc and current types of meter.

Work of the joint committee. Following receipt from the manufacturers of their draft of a standard specification, the Joint Committee met on March 9 and 10, 1920, as above noted, and proceeded to analyze and discuss the specifications submitted by the manufacturers.

It was at once decided to limit the Committee's work to specifications for disc meters, for several reasons, the most potent being that substantially all of the meters likely to be bought under competitive bidding belong to this class. It was also felt that if standard specifications for disc meters were adopted, after they had been in use a number of years the experience with them would indicate more clearly than can now be anticipated, the kind of specifications which should be prepared to cover other classes of meters.

During the year 1920 the sub-committee continued the investigation of various questions left unsettled by the Joint Committee, and finally reported back to the committee a revised draft of specifications, a statement of information which should be furnished to bidders in asking for bids under the specifications, a description of the tests necessary to determine whether meters complied with the specifications, and a list of the minimum equipment with which such tests could be made.

At the final meeting of the Committee on February 8 and 9, 1921, the material submitted by the sub-committee was discussed in detail and amended in some minor particulars, and then referred back to the sub-committee for submission to the manufacturers. Further slight modifications have been made as a result of comments by manufacturers, and the material as thus finally revised has been accepted by the Committee, through correspondence.

Acknowledgment. In presenting the proposed specifications to the two associations for their consideration, the Joint Committee wishes particularly to acknowledge its indebtedness to the meter manufacturers, who showed throughout an earnest desire to coöperate and to comply with all reasonable requirements, and particularly to standardize details of construction with the object of making

meters of various makes interchangeable in service, without rearrangement of connections.

April 7, 1921.

Respectfully submitted,
For the Joint Committee,
CHARLES W. SHERMAN, Chairman

N. E. W. W. Assoc. Committee
W. W. BRUSH, Chairman
CHARLES W. SHERMAN
A. W. F. BROWN
R. J. THOMAS
HENRY V. MACKSEY
JAMES A. MCMURRY
JOHN H. WALSH

Am. W. W. Assoc. Committee
C. M. SAVILLE, Chairman,
DOW R. GWINN
R. J. THOMAS
SETH M. VAN LOAN

Standard specifications for cold water meters, disc type

Cases. All meters shall have an outer case with a separate inner chamber in which the disc operates. The outer case for all 2-inch and smaller meters shall be of bronze composition. Cast-iron frost bottoms may be provided. The outer case for meters larger than 2 inches shall be of bronze composition or of cast iron protected by a non-corrosive treatment.

All meters shall have cast on them in raised characters the size and the model, and the direction of the flow through the meter shall be properly indicated. Meters larger than 1-inch shall be designed for easy removal of all interior parts, without disturbing the connections to the pipe line.

External bolts. All external bolts shall be made of bronze or of galvanized iron or steel. Nuts shall be designed for easy removal after having been long in service.

Registers. Registers may be either "round" or "straight" reading, indicating in cubic feet or gallons.

All parts of the registers shall be made of non-ferrous material. The maximum indication of the initial dial and the minimum capacity of the register when indicating cubic feet, shall be as follows:

Size inches	*Maximum indication of initial dial cu. ft.*	*Minimum capacity of register cu. ft.*
⅝	1	100,000
¾	10	1,000,000
1	10	1,000,000
1½	10	1,000,000
2	10	10,000,000
3	10	10,000,000
4	100	100,000,000
6	100	100,000,000

All dials, including the initial dial, shall be sub-divided into ten equal parts. All hands or pointers shall taper to a sharp point. They shall be accurately set and securely held in place.

Register boxes. Register boxes and lids shall be made of bronze composition or same material as the top case, with the name of the manufacturer cast on the lid in raised letters. The serial number of the meter shall be plainly stamped on the lid. If required, the serial number shall also be stamped on the case. The lid shall be recessed and shall lap over the box to prevent dirt from accumulating on the glass. The glass shall be inserted from the inside and securely held in place without the use of putty or pins. All register compartments shall be provided with a water-escape hole $\frac{1}{8}$ inch in diameter, placed so that the change gear or registering mechanism cannot be tampered with.

Connections for $\frac{5}{8}$*-,* $\frac{3}{4}$*-, and* 1*-inch sizes.* Spuds shall be threaded $\frac{3}{4}$, 1, and $1\frac{1}{4}$ inches respectively, male thread standard pipe size, and so threaded that Briggs standard pipe thread ring gages may be screwed on by hand within one thread of through the gage.

Over-all lengths of meters, face to face of spuds, shall be:

Size	*Length*
$\frac{5}{8}$ inch	$7\frac{1}{2}$ inches
$\frac{3}{4}$ inch	9 inches
1 inch	$10\frac{3}{4}$ inches

Couplings shall be made of bronze composition. Nuts shall be tapped $\frac{3}{4}$, 1 and $1\frac{1}{4}$ inches respectively, straight thread, standard pipe size and so tapped that Briggs standard pipe thread plug gages may be backed into the nuts by hand, i.e., the size of the thread in the nut is the maximum size of the Briggs plug but no larger. Tail pieces shall be threaded $\frac{1}{2}$, $\frac{3}{4}$ and 1 inch respectively, male thread, standard pipe size, and so threaded that Briggs standard pipe thread ring gages may be screwed on by hand, flush with the face of the gage.

Over-all lengths of tail pieces shall be:

Size	*Length*
$\frac{5}{8}$ inch	$2\frac{3}{8}$ inches
$\frac{3}{4}$ inch	$2\frac{1}{2}$ inches
1 inch	$2\frac{5}{8}$ inches

Connections for $1\frac{1}{2}$*-and* 2*-inch sizes.* Spuds shall be tapped $1\frac{1}{2}$ and 2 inches respectively, female thread, standard pipe size, and so tapped that Briggs standard pipe thread plug gages may be screwed on by hand up to the notch on the plug.

Over-all lengths of meters, face to face of spuds, shall be:

Size	*Length*
$1\frac{1}{2}$ inches	$12\frac{3}{8}$ inches
2 inches	$15\frac{1}{4}$ inches

Couplings shall be made of bronze composition. Nuts shall be tapped 2 and $2\frac{1}{2}$ inches respectively, straight thread, standard pipe size and so tapped that Briggs standard pipe thread plug gages may be backed into the nuts by hand, i.e., the size of the thread in the nut is the maximum size of the Briggs plug but no larger. Tail pieces shall be threaded $1\frac{1}{2}$ and 2 inches respectively, male thread, standard pipe size, and so threaded that Briggs standard

pipe thread ring gages may be screwed on by hand flush with the face of the gage. 2 by 1½-inch and 2½ by 2-inch standard pipe size malleable iron bushings are to be furnished with 1½-inch and 2-inch couplings respectively. Care should be taken to see that nuts as above described can be screwed on to the bushings by hand and that the face of the bushings will be sufficiently true and square to provide a proper packing surface.

Over-all lengths of tail pieces shall be:

Size	*Length*
1½ inches	2⅞ inches
2 inches	3 inches

Connections for 3, 4 *and 6-inch sizes.* Spuds shall be flanged, faced and drilled. Companion flanges shall be of cast iron, faced, dril ed and tapped. All dimensions, drilling and tapping shall conform exactly to American standard of January 1, 1914.

Over-all lengths of meters, face to face of flanges, shall be:

Size	*Length*
3 inches	24 inches
4 inches	29 inches
6 inches	36½ inches

Seal wire holes. ⅝, ¾, 1, 1½ and 2-inch meters shall have register box screws and coupling nuts drilled for seal wire holes. Meters larger than 2 inches in size shall have register box screws drilled for seal wire holes. All seal wire holes shall not be less than $\frac{3}{32}$ inch in diameter.

Measuring chambers. The measuring chamber for all meters shall be made of bronze composition and shall not be cast as part of the outer casing. It shall be machined with great care and secured in position in the outer casing so that any slight distortion of the casing which might take place under 150 pounds working pressure will not affect the sensitiveness of the meter.

Discs. Disc pistons shall be made of vulcanized rubber, and shall be fitted accurately but freely in their chambers. Vulcanized rubber pistons shall have a metal reinforcement or a thrust roller.

Intermediate gear trains. The intermediate gear trains shall be of such construction as to be easily removed and shall be made throughout of non-ferrous material. Gear spindles may run in bearings bushed with hard rubber provided the bushings are so constructed that they cannot drop out.

Strainers. All meters shall be provided with strainers except when self-strained by means of an annular space between the measuring chamber and the external case. Strainers shall be made of non-ferrous materials and shall fit tightly against the wall of the casing. They shall have an effective straining area as large as practicable and at least double that of the inlet.

Registration. The registration on the meter dial shall indicate the quantity recorded to be not less than 98 per cent nor more than 102 per cent of the water actually passed through the meter while it is being tested at rates of flow within the limits specified herein under "normal test flow limits." There shall be not less than 90 per cent of the actual flow recorded when a test is made at the rate of flow set forth under "minimum test flow."

Size, inches	*Normal test flow limits, gallons per minute*	*Minimum test flow, gallons per minute*
⅝	1 to 20	¼
¾	2 to 34	½
1	3 to 53	¾
1½	5 to 100	1½
2	8 to 160	2
3	16 to 315	4
4	28 to 500	7
6	48 to 1000	12

Capacity. New meters shall show a loss of head not exceeding 25 pounds per square inch, when the rate of flow is that given in the following table:

Size, inches	*Gallons per minute*
⅝	20
¾	34
1	53
1½	100
2	160
3	315
4	500
6	1000

Pressure test. Disc meters shall be guaranteed to operate under a working pressure of 150 pounds per square inch without leakage or damage to any part.

Workmanship and material. Disc meters shall be guaranteed against defects in materials and workmanship, for a period of one year from date of shipment. Parts to replace those in which a defect may develop within such period shall be supplied without charge, piece for piece, upon the return of such defective parts to the manufacturer thereof or upon proper proof of such defect.

Rejected meters. The manufacturer shall at his own expense, replace or satisfactorily readjust all meters rejected for failure to comply with these specifications.

Information to be furnished to meter manufacturers when requested to submit bids on disc meters

1. Meters shall conform to the standard specifications for cold water meters, disc type, adopted by the American and New England Water Works Associations.

2. The manufacturer shall state in his bid, the type of meter he proposes to furnish, as listed in his catalogue. The actual capacity of each size of meter called for is to be given graphically from 0 pounds up to 25 pounds loss of pressure. If this capacity be stated in the manufacturer's catalogue, reference may be made thereto.

3. No bid will be considered on meters of a design which has not been listed for at least one year in the catalogue regularly issued by the manufacturer.

4. The method of testing meters shall conform to that recommended by the Committee on standard specifications for water meters.

5. (a)* The meters are to be accepted on a certificate furnished by the manufacturers, that the meters have met the requirements of the standard specifications for water meters, as adopted by the American and New England Water Works Associations.

(b)* The meters will be tested by the purchaser to determine whether they do or do not comply with the standard specifications for water meters adopted by the American and New England Water Works Associations.

* *Note:* Sentence (a) is to be used where the purchaser does not have suitable equipment to test the meters. If he has such equipment then sentence (b) is to be used.

6. Registers shall be $\left\{\begin{matrix}\text{round}\\\text{straight}\end{matrix}\right\}$ reading and shall record in $\left\{\begin{matrix}\text{cubic feet}\\\text{gallons}\end{matrix}\right\}$

Equipment necessary to test meters for compliance with registration and capacity requirements as set forth in the standard specifications for water meters

The standard specifications require that meters shall accurately record the flow within certain limits and shall pass a given quantity of water with a maximum loss of pressure. Suitable equipment to make accurate tests must be available before the purchaser should make complaint of meters not complying with the specifications.

The minimum test equipment required for registration and capacity is as follows:

1. A quick-acting valve on the supply pipe through the use of which the flow can be started and stopped without appreciable loss of time.

2. A valve on the outlet side of the meter which can be used to establish the rate of flow desired.

3. Pressure gauges connected on both the inlet and outlet of the meter to show whether any material change in pressure occurs during the period of test which would affect the rate of flow. (The outlet pipe is to have sufficient head on it so that the meter will always have pressure on its outlet end and preferably not less than 5 pounds per square inch.)

4. A measuring device which may be either of the volumetric or weighing type. Whichever is used, the accuracy of determination of the volume or weight of water discharged into the measuring device must be such as to bring the limit of error within one-tenth of 1 per cent. (The volume of water passed must be sufficient to cause at least one or more revolutions of the pointer on the initial dial except for tests at "minimum test flow" rate. For the latter test, the amount passed shall not be less than one cubic foot.)

It is desirable to have available for testing meters a test table and appurtenances which are manufactured by several concerns. Such an outfit would include the equipment enumerated in the preceding four paragraphs.

For the capacity tests, it is necessary to add to the above equipment, two piezometer rings which must be of exactly the same diameter. The piezometer rings must be free from any burrs where the holes are drilled through the wall of the ring and not less than four holes shall be provided, drilled in

pairs and on diameters at right angles to one another. The inlet piezometer ring shall be set close to the meter, and shall be at a distance of not less than eight diameters from the nearest upstream stop cock or fitting in the supply pipe. The outlet piezometer ring shall be placed at a distance of not less than eight nor more than ten diameters from the outlet of the meter. The diameter of the piezometer rings and inlet and outlet pipes shall be the same as the size of the meter to be tested. The piezometer rings are to be connected by either rubber or metal tubing to a mercury U-tube. To this U-tube is to be attached an accurate adjustable scale for measuring the differences between the inlet and outlet pressures. Provision is to be made for the complete removal of air from the tubing connected with the U-tube, and the U-tube and the tubing connected therewith are to be so placed that the air will rise to the outlets. Where relatively high flows are to be recorded, it is necessary to read both sides of the mercury column to compensate, as far as practicable, for irregularities in the diameter of the glass U-tube, and such readings are to be made as nearly simultaneously as possible to avoid errors due to fluctuations.

Tests of meters recommended

The tests to be made on the meter are divided into two classes: 1, Capacity test; 2, registration test.

Capacity tests are those which test the design of the meter rather than the workmanship thereof. When a meter of a given make has once been tested for capacity, it should not be necessary to again test this type of meter unless a change has been made in its design.

The registration tests should be made on each meter, as the results are affected by workmanship and assembly of individual meters. There is no certainty that, because one meter of a given make comes within certain limits of accuracy, another meter of the same make turned out by the factory on the same day will necessarily give similar results. The register furnished with each meter should be used by both the manufacturer and purchaser in making registration tests. Where the purchaser does not have the necessary equipment to test the meters, there should be furnished by the manufacturer a certificate that each meter has been tested for accuracy of registration and complies with the standard specifications in this respect, and that the type of meter furnished has complied with the capacity requirements.

The registration tests recommended are as follows:

All meters should be tested for accuracy of registration within and as near as practicable to the low and high rates given under "Normal Test Flow Limits."

A test at the "Minimum Test Flow" should be made on as many as possible and not less than 5 per cent of the meters. If the results obtained from testing 5 per cent of the meters show that any meter does not comply with the low flow requirement, additional meters should be tested to the extent deemed necessary to make certain that the other meters do comply therewith.

The pressure test should be made on each size of meter furnished of a particular type. This pressure is to be 150 pounds per square inch and the pressure may be furnished through the use of a hand pump or such other

method as may be available. Before the meter has been tested by static pressure and also after it has been so tested, it should be tested for accuracy to see whether the meter has been so distorted as to affect registration. It is considered unnecessary to make a pressure test of each size of meter of a given type more than once if satisfactory results are obtained.

If it be possible to give a working pressure test under 150 pounds per square inch then such a test should be applied rather than a static pressure test.

SOCIETY AFFAIRS

SOCIETY BADGE

So many members have expressed a desire for the smaller association badge, about five-eighths of an inch in diameter, that the Secretary has obtained a supply, which can be had for a small sum.

CANADIAN SECTION

A meeting of the Canadian Section was held at the King Edward Hotel, Toronto, Ont., on February 4, 1921, the chairman of the section, Alexander Milne, presiding.

Gen. C. H. Mitchell, dean of the Faculty of Applied Science of the University of Toronto, introduced as the first speaker, outlined briefly the vital importance of water in community life and the great advances in technical and scientific knowledge during the last twenty years which make it possible to furnish safe supplies at reasonable cost even in congested districts. As a result of this scientific and technical progress, has come the need of special education for the men who look after the quality of public water supplies.

Dr. John W. S. McCullough, chief Provincial health officer of Ontario, introduced to speak on the relation of water supplies to the public health, stated that it is now believed goitre is among the diseases due to some defect in water supplies. Lead poisoning was mentioned as another disease due sometimes to defective water supply, but not of a bacterial character. The larger part of his address related to typhoid, cholera and dysentery, and the precautions taken against their spread by contaminated water supplies. As showing the difficulty of overcoming ignorant opposition to good water supplies needed to prevent the transmission of such diseases, Dr. McCullough referred to an experience of an American health officer in the Philippines. In his district the natives drank water infected with amoeba causing dysentery. He sank several artesian wells which gave a wholesome supply, but the natives refused to drink it because the water came from the neighborhood of Hell. Some of these natives were afflicted with hookworm and a particu-

larly bad case was treated with thymol and recovered. This case was given the well water, which the natives knew, but they did not know about the thymol. The cure was attributed by them to the artesian water, which immediately became popular.

In the Province of Ontario, there are rather strict public health regulations regarding new water and sewerage works, and the plans for such works must be approved by the provincial health officer before work can be done. Last year over $7,000,000 worth of such work was approved. One interesting feature of the public health work has been the general improvement in health observed where a good quality of water supply is uninterruptedly maintained.

Fire hydrant troubles were discussed informally by A. L. Dobbin, of Peterboro, Ont. The mains there were laid with a minimum cover of 5 feet, but in regrading the streets the mains were sometimes left with only 3 feet cover. During very cold weather there was no trouble with freezing of the mains, but a great deal of trouble was experienced with hydrants freezing below the barrel. The hydrants are all in gravel, without ground water. A remedy for the freezing has been to connect a 45-degree bend to the main, then put in a length of straight pipe on a 45-degree slope, attach a 45-degree bend to the bottom of this pipe and run the hydrant branch, with a gate on it, from this bend to the hydrant. The latter is supported on a concrete box 24 inches square and 3 feet high, with the valve of the hydrant 7½ feet below the surface of the ground. In some cases a wooden box was placed around the base of the hydrant and a steam pipe run down to it from the surface. By turning steam through the pipe to the box no trouble with freezing has been experienced in the coldest weather.

The subject was discussed by Messrs. Proctor, Diven, Harris, Randall, Wynne-Roberts, Dallyn, Storey, Milne and Knight.

A paper on "Development of the F. M. Double Check Valve as a Safeguard for Public Water Supplies" was presented by H. A. Burnham and discussed by Messrs. Wynne-Roberts, Diven, Dallyn, Harris, Powell, Scofield, Fairchild, Fuller, Buchanan, Gore, Miller, Hiller, Milne and Archibald. At the close of the discussion it was voted that a committee of the Section should be appointed to cooperate with the Provincial Board of Health in drafting regulations covering all physical connections between a municipal water works system and any outside source of water supply. The acting chair-

man, Mr. Dallyn, appointed Mr. Powell of Toronto, Mr. Fuller of Chatham, Mr. Dobbin of Peterboro, Mr. Gray of Hamilton and Mr. Milne of St. Catherines members of this committee.

ILLINOIS SECTION

The Illinois Section held a joint meeting with the Iowa Section at Hotel LaSalle, Chicago, on March 23–24. This was the thirteenth annual meeting of the Illinois Section, but 13 did not prove to be a number of ill omen, for the attendance was about a hundred.

In addition to the reports of the officers, the following papers were presented:

"Hydrogen-Ion Concentration; What It Is," by R. Edman Greenfield, chemist of the State Water Survey, Urbana, Ill.

"Operation of the Evanston and Whiting Filters," by S. A. Greeley, consulting engineer, Chicago.

"Fixing of Rates for Public Utilities by Contract," by Walter A. Shaw, formerly a member of the Illinois Public Utility Commission.

"Operating a Water Works Plant under State Supervision," by C. M. Ross, superintendent, Cairo Water Company.

"Impounding Water at Bloomington," by D. H. Maxwell, assistant engineer, Alvord & Burdick, Chicago.

"The Iowa Bunch—How They Do It," by C. R. Henderson, manager, Davenport Water Company.

"What a President-Elect Thinks About," by Col. Edward Bartow, President-elect, American Water Works Association.

"Retrospect and Glimpse of the Future of the Water Supply of Chicago," by John Ericson, consulting engineer, Chicago.

"Down the Main Drainage Canal by Movie," by Langdon Pearse, sanitary engineer, Sanitary District of Chicago.

During the meeting the members and guests were given an opportunity to visit the Chicago Avenue, Lake View and Mayfair pumping stations. The City of Chicago was the host on this occasion and provided the automobiles for the visit.

The following officers were elected for the following year:

Chairman, John W. Alvord, consulting engineer, Chicago.

Vice-chairman, Henry Ringness, Peoria Water Company, Peoria, Ill.

Treasurer, H. E. Keeler, Chicago, Ill.

Trustee, A. M. Buswell, chief, State Water Survey, Urbana, Ill.

The above officers reappointed G. C. Habermeyer, Urbana, as secretary.

NEW YORK SECTION

A meeting was held at the Hotel McAlpine on February 16 at which representatives of makers of trenching machines explained the operation of such apparatus. Both lantern slides and moving pictures were used for illustrating the remarks, and there was a brief discussion.

ADDITIONS TO MEMBERSHIP

Active Members

J. G. Archibald, Superintendent Water Works System, Woodstock, Ont.

John G. Bailey, Superintendent Water Distribution, Engineer building, Main and Orange Streets, Jacksonville, Fla.

Ralph D. Bates, Chemist, Filter Plant, Clarksburg, W. Va.

J. F. Bradley, Chief Engineer and Bacteriologist, R. F. D. 8, Valparaiso, Ind.

Edward Brown, Superintendent Water Works, Eau Claire, Wis.

Egbert D. Case, Vice-President Pitometer Company, 50 Church Street, New York, N. Y.

Leonard Clarke, District Manager, Box 666, Vancouver, Wash.

O. E. Clemens, Manager Water Sales, Spring Valley Water Company, 375 Sutter Street, San Francisco, Calif.

Edward Drake, Civil Engineer, New Bedford, Mass.

Almon L. Fales, Consulting Engineer, 14 Beacon Street, Boston, Mass.

T. E. Ferris, Chairman Water Commissioners, Niagara Falls, Ont.

W. S. Finlay, Jr., Vice President American Water Works and Electric Company, 50 Broad Street, New York.

Geo. H. Finneran, Superintendent Water Service, 710 Albany Avenue, Boston, Mass.

William Flannery, Mechanical Engineering Division, Department Water Supply, Gas and Electricity, 9 Park Avenue, Brooklyn, N. Y.

Ole Forsberg, Chemist, Oliver Iron Mining Company, Hibbing, Minn.

G. C. Francis, Superintendent Sprinkler Risk Department, Canadian Fire Underwriters Association, Toronto, Ont.

Alexander Grant, Civil Engineer, 6 Queensgate, Inverness, Scotland.

Norman J. Goebel, B.Sc., Water Works Engineer, City Hall, Oshawa, Ont.

Charles R. Gow, Engineer and Contractor, 25 Montview Street, West Roxbury, Mass.

H. J. Harder, City Engineer, 692 Fourteenth Avenue, Paterson, N. J.

Charles D. Howard, Chemist, State Board of Health, Concord, N. H.

Alexander Hutchinson, C. E., Drummond, McCall and Company, P. O. Box 660, Montreal, P. Q.

Will A. Hutchins, Secretary and Superintendent, 196 Van Buren Street, Freeport, Ill.

C. E. Inman, Commissioner and Superintendent Water Works, Warren, O.

C. A. Landback, President Board Water Commissioners, 186 Market Street, Perth Amboy, N. J.

John V. Lewis, Engineer in Charge, Sewage Disposal Works, 4 Nott Terrace, Schenectady, N. Y.

Daniel F. McCarthy, Manager Lawrence Park Realty Company, Bronxville, N. Y.

Frederick G. Merckel, Sanitary Engineer, Wallace & Tiernan Co., 707 Commerce Building, Kansas City, Mo.

F. McArthur, City Engineer, Guelph, Ont.

Geo. H. Mitchell, Superintendent Water Works, City Hall, Toronto, Ont.

Harvey T. Munn, Hydraulic Engineer, National Board of Fire Underwriters, 76 William Street, New York, N. Y.

E. Fred Muser, Superintendent Clear Springs Water Co., Post Office Building, Catasauqua, Pa.

Robert Harrison Myers, Public Utility Manager, Stratford, Ont.

Edward M. Proctor, Consulting Engineer, 20 Rosemount Avenue, Toronto, Ont.

Alex. G. Reisweber, Superintendent N. F. Division, Western New York Water Company, 401 Elderfield and Hartshorn Building, Niagara Falls, N. Y.

Edwin G. Reynolds, Jr., Civil Engineer, New Rochelle Water Company, 514 Main Street, New Rochelle, N. Y.

James H. Reynolds, Assistant Superintendent Water Works, 66 Highland Avenue, Lowell, Mass.

Arthur T. Safford, Consulting Engineer, Proprietors of Locks and Canals, 66 Broadway, Lowell, Mass.

W. B. Savage, Superintendent Water Works, Knoxville, Iowa.

William Scott, Assistant Superintendent Filtration Plant, Centre Island, Toronto, Ont.

Frank J. Schrieber, Chief Inspector Bureau of Water, Buffalo, N.Y.

John J. Sharon, Assistant to Manager, Spring Valley Water Company, 375 Sutter Street, San Francisco.

George M. Shepard, Consulting Engineer with Louis P. Wolff, 1000 Guardian Life Building, St. Paul, Minn.

Alfred E. Skinner, District Manager, Pitometer Co., 1324 East 26th Street, Kansas City, Mo.

Spencer W. Stewart, President Ambursen Construction Company, 186 Fifth Avenue, New York, N. Y.

Henry A. Symonds, Consulting Hydraulic Engineer, 75 Crofton Road, Waban, Mass.

Sturgis H. Thorndike, Consulting Engineer, 15 Beacon Street, Boston, Mass.

William John Turnbull, Chief Engineer and Master Mechanic, State Farm, Mass.

Charles D. Vail, Railway and Hydraulic Engineer, Public Utility Commission, Denver, Colo.

Lewis Dewar Walker, Water Works Engineer, Canadian Fire Underwriters Association. Excelsior Life Building, Toronto, Ont.

S. W. Webb, District Manager, Consumers Power Company, Cadillac, Mich.

James E. Williamson, Consulting Engineer, 39 Cortlandt Street, New York.

Corporate Member

Borough of Totowa, N. J.

Associate Members

Ambursen Construction Company, Inc., 186 Fifth Avenue, New York.

Art Concrete Works, P. O. Box. 417, Pasadena, Cal.

Drummond, McCall & Company, Ltd., Montreal, P. Q.

Leslie R. Milford, Laboratory Manager, Solvay Process Company, Syracuse, N. Y.

M. E. Mutchler, Sales Manager, Sterling Engine Company, Buffalo, N. Y.

Payne Dean, Limited, 103 Park Avenue, New York, N. Y.

DEATHS

George D. Westover, Cadillac, Mich., died April 24, 1920.

Robert Albert McKim, New York, died May 14, 1920.

L. E. Murphy, Jacksonville, Fla., died August 28, 1920.

Jerry O'Shaughnessy, Columbus, Ohio, died January 28, 1921.

William A. Hostetler, Superintendent Iowa City Water Works, Iowa City, Iowa, died, February 1921.

F. W. Shepperd, New York, N. Y., died February 8, 1921.